PATENT ABSTRACTS OF JAPAN

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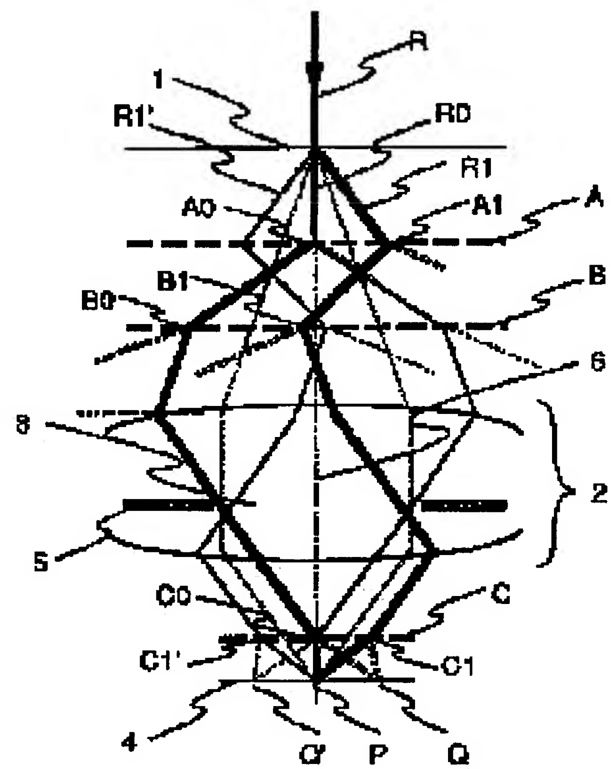
(54) METHOD AND APPARATUS FOR PROJECTION EXPOSING

(57)Abstract:
PURPOSE: To improve the resolution exceeding the diffraction limit by emitting the light from a light source to a mask, diffracting the pattern of the mask, diffracting the diffracted light through a projection optical system, and reproducing the pattern on a sample to be exposed.
CONSTITUTION: A mask 1 is inserted between a projection optical system 2 and diffraction gratings A, B, and a diffraction grating C is inserted between the system 2 and a wafer 4. In this case, the gratings A, B, C are simultaneously phase gratings. The light R perpendicularly incident to the mask 1 is diffracted to zero order diffracted light R0, + primary diffraction light R1 and - primary diffracted light R1' on the mask surface. The light R0 arrives at a point A0 on the grating A, and the light diffracted in the - primary direction is diffracted to + primary direction at the point B0 on the grating B. Thereafter, it is diffracted at the point C0 on the grating C via the left end of the pupil 3 in ± primary direction, and arrived at two points Q, P on the image surfaces.



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CLAIMS

[Claim(s)]
[Claim 1] The projection exposure approach characterized by consisting of the process for which a mask is prepared, the process which irradiates the light from the light source at the above-mentioned mask, the process which diffracts the pattern of the above-mentioned mask, and the process which diffracts the this diffracted light through projection optics, and reproduces and exposes the above-mentioned mask pattern on a sample.
[Claim 2] The projection exposure approach according to claim 1 characterized by diffracting twice as the above-mentioned process which carries out diffraction.
[Claim 3] the light source, the 1st and the 2nd diffraction means irradiates the pattern on a mask with the light from this light source, and diffract the light from this mask, the projection optics that project the diffracted light on a sample, and the 3rd diffraction means which diffracts the light from this projection optics -- this -- the projection aligner characterized by to consist of a sample base in which the sample arranged under the 3rd diffraction means lays.
[Claim 4] The above 1st and the 2nd diffraction means are a projection aligner according to claim 3 characterized by being a phase grating.
[Claim 5] In the approach of forming a pattern on the above-mentioned substrate by irradiating at a mask the light of the wavelength lambda which emitted the light source through an illumination-light study system, and carrying out image formation of the pattern on the above-mentioned mask to up to a substrate according to the projection optics of numerical aperture NA and reduction percentage M:1 So that it may have the 1st parallel diffraction grating with the above-mentioned substrate between the above-mentioned substrate and the above-mentioned projection optics and the image of a mask pattern may be reproduced by interference of the light diffracted by said 1st diffraction grating near the substrate side The projection exposure approach characterized by preparing the diffraction grating, the 2nd diffraction grating and the 3rd diffraction grating, of two sheets sequentially from the above-mentioned mask side at the above-mentioned mask and parallel between the above-mentioned mask and the above-mentioned illumination-light study system.
[Claim 6] The projection exposure approach according to claim 5 characterized by the cutoff spatial frequency f of the optical system which prepared said diffraction grating being larger than the cutoff spatial frequency f0 of the optical system which does not prepare said diffraction grating, and being 2 double less or equal of f0.
[Claim 7] The space period P1 of said 1st diffraction grating is the projection exposure approach according to claim 5 characterized by being in the range of lambda/(1.42, NA) <=P1 <= lambda/NA.

[Claim 8] It is the projection exposure approach according to claim 5 characterized by the periodic direction of the 1st, 2nd, and 3rd diffraction gratings of the above being equal, and the space period P1 of the 1st diffraction grating of the above, the space period P2 of the 2nd diffraction grating, and the space period P3 of the 3rd diffraction grating filling the relation of about 1/P 3= 1/P2-1/(M-P1).
[Claim 9] It is the projection exposure approach according to claim 5 characterized by optical paths Z2 and Z3 filling /P2= (Z3-/M+Z1andM) / relation of P1 mostly (Z3-Z2) from an optical path Z1 and the above-mentioned mask front face of the 2nd and 3rd diffraction grating of the above from the above-mentioned substrate front face of the 1st diffraction grating of the above.
[Claim 10] Each installation location of the 1st diffraction grating of the above, the 2nd diffraction

grating of the above, and the 3rd diffraction grating of the above, The thickness of each transparence substrate which prepares the 1st diffraction grating of the above, the 2nd diffraction grating of the above, and the 3rd diffraction grating of the above, And the projection exposure approach according to claim 5 characterized by setting up the period of the 2nd diffraction grating of the above according to the physical relationship of NA of said projection optics and a contraction scale factor, and the each diffraction grating and the above-mentioned substrate so that the aberration between the above-mentioned mask side and the image surface may serve as min.
[Claim 11] The space period P2 of said 2nd diffraction grating is P2 <=1/(1-2 and NA/M). ******** -- the projection exposure approach according to claim 5 characterized by things.
[Claim 12] Said 2nd and 3rd diffraction gratings are the projection exposure approaches according to claim 5 characterized by being a phase grating.
[Claim 13] Said 1st diffraction grating is the projection exposure approach according to claim 5 characterized by being a phase grating.
[Claim 14] Between said substrate and said 1st diffraction grating, the width of face to said one direction by below Z1 and NA While a space period prepares the about 2, Z1, and 1st [of NA] protection-from-light pattern [whether the protection-from-light pattern of the above 1st on a mask and the 2nd protection-from-light pattern which shades a field / **** / almost / are prepared in right above / of said mask /, or directly under, and an exposure field is restricted to it, and] Or the projection exposure approach according to claim 5 characterized by scanning and exposing on a substrate the exposure field by which the limit was carried out [above-mentioned], or exposing, moving in the shape of a step.
[Claim 15] Said diffraction grating is the projection exposure approach according to claim 5 which is a 1-dimensional diffraction grating and is characterized by carrying out aberration amendment so that the wave aberration of said projection optics may serve as axial symmetry centering on the diameter of a direction perpendicular to the periodic direction of the above-mentioned diffraction grating on a pupil.
[Claim 16] Said mask is the projection exposure approach according to claim 5 characterized by including a periodic mold phase shift mask.
[Claim 17] Said mask is the projection exposure approach according to claim 5 characterized by having a detailed pattern in the specific direction according to said the 1st period and direction of a diffraction grating.
[Claim 18] Said mask is the projection exposure approach according to claim 5 characterized by amending a pattern configuration according to said the 1st period and direction of a diffraction grating.
[Claim 19] The projection exposure approach according to claim 5 characterized by for the refractive index n having filled between said 1st diffraction grating and said substrates with the larger liquid than 1, and setting NA of said projection optics as the range of 0.5<NA<n/2.
[Claim 20] In the projection aligner which has the projection optics of the numerical aperture NA which carries out image formation of the pattern on the above-mentioned mask to the illumination-light study system which irradiates the light of the wavelength lambda which emitted the light source at the mask on a mask stage near the substrate front face on a substrate stage, and reduction percentage M:1 It has the 1st diffraction grating of the above-mentioned substrate and 1st parallel space period P1 (lambda/(1.42, NA) <=P1 <= lambda/NA) between the above-mentioned substrate and the above-mentioned projection optics. So that the image of a mask pattern may be reproduced by interference of the light diffracted by the 1st diffraction grating of the above near the substrate side The projection aligner characterized by having the diffraction grating, the 2nd diffraction grating and the 3rd diffraction grating, of two sheets sequentially from the above-mentioned mask side in the above-mentioned mask and parallel between the above-mentioned mask and the above-mentioned illumination-light study system.
[Claim 21] It is the projection aligner according to claim 20 characterized by the periodic direction of the 1st, 2nd, and 3rd diffraction gratings of the above being equal, and the space period P1 of the 1st diffraction grating of the above, the space period P2 of the 2nd diffraction grating, and the space period P3 of the 3rd diffraction grating filling the relation between 1/P3=1 / (M-P1) +1/P2 mostly.
[Claim 22] Each installation location of the 1st diffraction grating of the above, the 2nd diffraction grating of the above, and the 3rd diffraction grating of the above, The thickness of each transparence

substrate which prepares the 1st diffraction grating of the above, the 2nd diffraction grating of the above, and the 3rd diffraction grating of the above, And the projection aligner according to claim 20 characterized by setting up the period of the 2nd diffraction grating of the above according to the physical relationship of NA of said projection optics and a contraction scale factor, and the each diffraction grating and the above-mentioned substrate so that the aberration between the above-mentioned mask side and the image surface may serve as min.

[Claim 23] The projection aligner according to claim 20 characterized by having the function exposed while the width of face to said one direction scans and exposes on a substrate the exposure field which a space period has the protection-from-light pattern of 2 and NA-Z1 mostly, or was restricted with the above-mentioned protection-from-light pattern by below Z1 and NA or moves in the shape of a step between said substrate and said 1st diffraction grating.

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DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]
[Industrial Application] This invention relates to the pattern formation approach for forming the detailed pattern of various solid-state components, and the projection aligner used for this.
[0002]
[Description of the Prior Art] In order to improve the degree of integration and working speeds of a solid-state component, such as LSI, detailed-ization of a circuit pattern is progressing. Moreover, detailed-ization of a pattern is desired for improvement in a property, such as light and electronic devices, such as laser, and various kinds of quantum effectiveness components, a dielectric, a magnetic-substance component. The reduced-projection-exposure method excellent in mass-production nature and definition ability is widely used for such pattern formation now. Since the resolution limit of this approach is proportional to exposure wavelength and in inverse proportion to the numerical aperture (NA) of a projection lens, improvement in the resolution limit has been performed by short-wavelength-izing and high NA-ization.
[0003] Moreover, the various image improving methods, such as a phase shift method, deformation illumination (oblique incidence illumination), and the pupil filter method, are applied as technique for improving the resolution of a reduced-projection-exposure method further. these -- the former -- the engine performance of optical system -- until [theoretical] diffraction marginal (cutoff spatial frequency = 2 NA/lambda) last-minute -- it will be used effectively The these images improving method (often called a super resolution method) is discussed by the 49th page (the Science forum company **, 1994, Tokyo) from innovation of a ULSI lithography technique, Chapter 1, and the 34th page, for example.
[0004] On the other hand, some methods of expanding the spatial-frequency band of optical system are learned as an approach of improving the resolution of a microscope across the conventional above-mentioned diffraction limitation. These spatial-frequency band dilation is discussed by the 859th page (1968) from application physics, the 37th volume, No. 9, and the 853rd page, for example. One of approaches of this scans two grid patterns, keeping conjugation relation mutual right above [of a body and an image] (at least inside of the depth of focus), they form a moire pattern by superposition of a body and the 1st grid pattern of the right above of it, and get over by passing a lens system and piling up this moire pattern with the 2nd grid pattern by the image side. Since a moire pattern has spatial frequency lower than a body and the 1st grid pattern, it can pass a lens system. It applies for applying this approach to a reduced-projection-exposure method. Generally, since it is difficult, it is operating scanning a grid pattern mechanically right above [wafer] as a grid by preparing a phot chromics material directly on a wafer, and scanning an interference fringe in piles to this.
[0005]
[Problem(s) to be Solved by the Invention] however, the above -- there are the following technical problems in various conventional techniques.
[0006] As for short-wavelength-izing of exposure light, ArF excimer laser (wavelength of 193nm) is first considered to be a limitation from the problem of the permeability of an optical (lens) ingredient. Moreover, as for NA of projection optics, 0.6-0.7 are considered to be limitations from the problem on a lens design and manufacture. However, the resolution limit of the exposing method

is 0.3 lambda/NA extent, when 0.5 lambda/NA and a periodic mold phase shift method are generally used, therefore even if it uses the limitation of the above-mentioned short-wavelength-izing and a raise in NA, a pattern 0.1 micrometers or less is conventionally difficult for formation. Moreover, by the describing [above] periodic mold phase shift method, since a mask pattern is restricted, an actual limit size retreats further about a more common circuit pattern. Moreover, although expansion of exposure area is demanded with large-scale-izing of LSI, it is very difficult to be satisfied with coincidence of expansion of the exposure field of projection optics, and the demand of a raise in NA.

[0007] On the other hand, the various spatial-frequency band dilation aiming at crossing the conventional diffraction limitation aims at expanding a minute body for a microscope. For this reason, there was a trouble that it was not necessarily suitable in forming the minute optical image demanded by optical lithography. For example, by the approach of using said moire pattern, the device or optical system for scanning two grids, keeping conjugation relation mutual right above [of a mask and a wafer] becomes it is remarkable and complicated. Since exposure of a resist is substantially performed with EBANESSENTO light, there are problems, like it becomes difficult for light to decline in a wavelength range and to expose a thick resist. Furthermore, even when using phot clo MIKKU, there is no suitable ingredient. Therefore, when mass production method of LSI was considered, there was a trouble that it could not necessarily be said that it is practical.

[0008] The purpose of this invention is in the projection exposing method which forms the detailed pattern of various solid-state components to offer the approach of improving the resolution across the conventional diffraction limitation (cutoff spatial frequency). Specifically, it is in offering the new projection exposure approach that effectiveness almost equivalent to having a maximum of doubled the NA substantially is acquired, and the aligner which makes this possible, without changing NA of projection optics.

[0009] Another purpose of this invention is to offer the projection exposure approach of having been suitable for mass production method of LSI which is satisfied only with adding some amelioration to these of the big exposure field and high resolution at coincidence possible [the thing of the improvement effectiveness in resolution to acquire], without changing greatly the configuration and optical system of an aligner of a conventional type.

[0010]

[Means for Solving the Problem] In case image formation of the above-mentioned purpose is carried out to up to a substrate using the light of wavelength lambda according to the projection optics (numerical aperture = NA, reduction percentage =1:M) of MASUKUPATAN ** and a pattern is formed, between the above-mentioned substrate and the above-mentioned projection optics While preparing the 1st diffraction grating of the space period P1 (however, it is desirable that it is lambda/ (1.42, NA) <=P1 <= lambda/NA) in the above-mentioned substrate and parallel So that the image of a mask pattern may be reproduced by interference of the light diffracted by the 1st diffraction grating of the above near the substrate side It is attained by preparing the diffraction grating, the 2nd diffraction grating and the 3rd diffraction grating, of two sheets sequentially from the above-mentioned mask side between said projection optics and said masks at the above-mentioned mask and parallel.

[0011] In order to reproduce the image of a mask pattern faithfully by the diffracted light of the 1st diffraction grating, the periodic direction of the 1st, 2nd, and 3rd diffraction gratings of the above is equal, and the space period P1 of the 1st diffraction grating of the above, the space period P2 of the 2nd diffraction grating, and the space period P3 of the 3rd diffraction grating are set up so that the relation of about 1/P 3= 1/P2-1/(M-P1) may be filled. Moreover, the optical path Z1 from the above-mentioned substrate front face of the 1st diffraction grating of the above and the optical paths Z2 and Z3 from the above-mentioned mask front face of the 2nd and 3rd diffraction grating of the above are set up so that /P2= (Z3-/M+Z1andM) / relation of P1 may be filled mostly (Z3-Z2). Furthermore, it is desirable that it is P2<=1/(1-2 and NA/M). Moreover, it is desirable to set up the thickness of the installation location of the 1st, 2nd, and 3rd diffraction grating and the transparence substrate of each diffraction grating and the period of the 2nd diffraction grating so that the aberration between the above-mentioned mask side and the image surface may serve as min. Moreover, it is desirable that a space period prepares the 2nd protection-from-light pattern which shades a field [**** / right

above / of said mask / or directly under / again / as the protection-from-light pattern of the above 1st / almost] for the about 2, Z1, and 1st [of NA] protection-from-light pattern, and width of face restricts an exposure field by below Z1 and NA between a substrate and the 1st diffraction grating. Furthermore, it is desirable to scan and expose on a substrate the exposure field by which the limit was carried out [above-mentioned] if needed, or to expose, moving in the shape of a step. As for each [these] diffraction grating, it is desirable that it is a phase grating.
[0012] In addition, as for said diffraction grating, it is desirable to consider as a 1-dimensional diffraction grating, and to carry out aberration amendment of the wave aberration of said projection optics so that it may become axial symmetry centering on the diameter of a direction perpendicular to the periodic direction of the above-mentioned diffraction grating on a pupil. Moreover, this invention demonstrates big effectiveness especially, when a periodic mold phase shift mask is used as a mask. Furthermore, it is desirable to restrict the period and direction of a detailed pattern, or to amend a pattern configuration according to the period and direction of a diffraction grating, if needed. Moreover, if a refractive index n fills between the 1st diffraction grating and said substrates with a larger liquid than 1 and NA of said projection optics is set as the range of $0.5<NA<n/2$, formation of a still more detailed pattern will be attained.
[0013]
[Function] This invention will acquire effectiveness equivalent to increasing NA effectually by preparing a diffraction grating between the last element of projection optics, and a wafer, and enlarging the incident angle of the light beam which carries out incidence to a wafer side. However, only by preparing a diffraction grating between the lens-wafers of optical system conventionally simply, the diffracted lights which should originally be collected to one on the image surface are scattered all over the scattering location on the image surface, and playback of a mask pattern is difficult absolutely. Therefore, it is necessary to reconfigurate optical system so that an image faithful to the original mask pattern may be reproduced as a result of interference. And as for the viewpoint of practicality to such optical system, it is desirable that the conventional mask is moreover usable, without converting the conventional projection optics greatly. This invention satisfies these demands so that it may state below.
[0014] In order to explain an operation of this invention, the principle of the image formation by this invention is explained as compared with a conventional method. The situation of the image formation at the time of illuminating a mask or a phase shift mask the case where it illuminates to a perpendicular respectively, and aslant, conventionally by the conventional projection exposure optical system is shown in drawing 2 a, b, c, and d for the again comparison with drawing 1 of the image formation in the optical system based on one gestalt of this invention. In any drawing, 2:1 contraction optical system, coherent illumination, and a 1-dimensional pattern were assumed, and paraxial image formation approximation was carried out.
[0015] First, when the vertical illuminator of the mask is usually conventionally carried out by optical system (drawing 2 a), it diffracts with the pattern on a mask, and the beam of light which passed the pupil 24 (inside of diaphragm 20) of projection optics 23 among the diffracted lights converges on the image surface 25, it interferes in the light 22 which carried out vertical incidence to the transparency mold mask 21, and it forms a pattern. Here, if the pattern period which gives the greatest angle of diffraction which can pass a pupil is defined as the resolution limit, the resolution limit will become lambda/(2NA) (however, NA=sin theta 0). Furthermore, if the periodic mold phase shift mask 26 is applied to this optical system, as shown in drawing 2 b, the zero-order diffracted light will disappear and the diffracted light will arise in the symmetry to an optical axis 29 (alternate long and short dash line in drawing). For this reason, the greatest angle of diffraction which can pass a pupil becomes twice, and the resolution limit improves to lambda/(4NA).
[0016] moreover -- if slanting lighting is conventionally applied to optical system (it was assumed that the zero-order light 27 of the mask diffracted light passed through the left end of ****** since it was easy, drawing 2 c and) -- the inside of the mask diffracted light -- a core [light / zero-order] -- carrying out -- positive/negative -- only a single-sided component (drawing +primary light 28) with one of angle of diffractions passes a pupil, and converges on the image surface. Since the diffracted light which has a twice [in the case of vertical incidence] as many angle of diffraction as this can pass a pupil, the resolution limit becomes lambda/(4NA) too. However, in order to use only one side

of a diffraction spectrum, the resolution of an isolated pattern is not different from the case of a vertical illuminator, and has the problem of contrast falling also in the case of a periodic pattern. Furthermore, since two or more diffracted lights cannot pass a pupil if a mask is changed into the periodic mold phase shift mask 26, a pattern is not resolved (drawing 2 d).

[0017] Next, the image formation in the optical system based on one gestalt of this invention is shown in drawing 1 . In the conventional optical system of drawing 2 , a diffraction grating A and a diffraction grating B are inserted between a mask 1 and projection optics 2, and, as for it, the optical system of drawing 1 inserts a diffraction grating C between projection optics 2 and a wafer 4 again. Here, let both the diffraction gratings A, B, and C be phase gratings.

[0018] The light R which carried out vertical incidence to the mask 1 is diffracted by the zero-order diffracted light R0, the +primary diffracted light R1, and -primary diffracted-light R1' in respect of a mask. the zero-order light R0 should reach the point A0 on a diffraction grating A, and the light diffracted in the -primary direction there should pass the left end of a pupil 3 (inside of diaphragm 5), after being diffracted in the +primary direction the point B0 on a diffraction grating B -- it diffracts in the primary [**] direction the point C0 on a diffraction grating C -- having -- an each image surface top -- two points are given to Q and P. Moreover, the +primary diffracted light R1 reaches the point A1 on a diffraction grating A, and after the light diffracted in the -primary direction there is diffracted in the +primary direction the point B1 on a diffraction grating B, it is diffracted in the primary [**] direction the point C1 on a diffraction grating C through the right end of a pupil 3, and reaches the points Q and P on the image surface too. on the other hand -- a point -- A -- zero -- + -- one -- order -- a direction -- diffracting -- having had -- zero-order -- light -- R -- zero -- ' - one -- order -- the diffracted light -- R -- one -- ' -- receiving -- an optical path -- the above-mentioned optical path and above-mentioned optical axis 6 (alternate long and short dash line in drawing) of two beams of light -- receiving -- the symmetry -- becoming . That is, finally both are diffracted in the primary [**] direction the point C0 on a diffraction grating C, and reach the point P on the image surface, and Q'. Therefore, three beams of light, the zero-order light diffracted with the mask and the primary [+] -primary beam of light, cross at P points. This [depend / on a mask angle of diffraction] is clear. Therefore, at Point P, a diffraction figure is reproduced faithfully.

[0019] Since the diffracted light with a twice as many angle of diffraction as this can pass a pupil using the optical system which has the same NA and a scale factor compared with a conventional method (drawing 2 a), the effectiveness same with having doubled NA two substantially is acquired. moreover -- slanting lighting (drawing 2 b) -- a core [light / zero-order] -- carrying out -- positive/negative -- either -- since the diffracted light of both sides is reproducible by this invention in the image surface to only diffracted light of one of the two being reproducible in the image surface, with slanting lighting, the improvement in resolution of the difficult isolated pattern is possible, and big contrast can be acquired to a periodic pattern. Furthermore, if a periodic mold phase shift mask is applied to this optical system (drawing 3 a), as a result of +primary light R+ and -primary light R- which the zero-order diffracted light disappears and have a twice [usual] as many angle of diffraction as this interfering, the degree of minimum solution image becomes lambda/(8NA). This is the one half of lambda/(4NA) which is a theoretical limitation at the time of using a periodic mold phase shift mask and slanting lighting until now, and improvement in fast resolution of it is attained by this invention. Moreover, the situation of the image formation at the time of applying slanting lighting in this optical system is shown in drawing 3 b. With slanting lighting, it becomes possible to pass a pupil to diffracted-light R1" which has a big angle of diffraction only to one side, and resolution can be improved to a maximum of the twice (8NA), i.e., lambda/, at the time of a vertical illuminator. Moreover, if various illumination light from which a mask incident angle differs is used, the effectiveness of partial coherent illumination can be acquired completely similarly in optical system conventionally.

[0020] It is as follows when the principle of this invention is explained from the position of the fourier diffraction theory (drawing 4). By the following explanation, the scale factor of optical system shall consider 1 in a phase grid, and a diffraction grating shall consider only the about 1-dimensional primary [**] diffracted light. From the point P on the image surface, when a pupil 3 is seen through a diffraction grating C, a pupil is divided into two by diffraction and it is visible (drawing 4 a). In each pupil, the mask Fourier transform image which passes a pupil at an angle of

the specification which exists respectively appears. On the other hand, considering a mask side, the light diffracted with the mask is diffracted by diffraction gratings A and B, and forms two or more mask Fourier transform images on a pupil. Among these, a certain thing which passed the pupil at an angle of specification can be seen in the pupil which was visible in the top (drawing 4 b). That is, in the case of drawing 4 , the fourier diffraction figure on the right of drawing 4 b appears in the pupil on the left-hand side of drawing 4 a, and the fourier diffraction figure of Hidari of drawing 4 b appears in the pupil on the right-hand side of drawing 4 a. At this time, conditions to reproduce an image correctly at Point P are the following two points.

[0021] (1) The spectrum of the same point on a mask should appear through two pupils.

[0022] (2) Two spectrums should connect continuously at the contact of two pupils.

[0023] It is necessary to enable it in other words to see one continuous spectrum through two or more pupils.

[0024] from an image -- seeing -- a diffraction grating C -- minding -- f' -- two or more shifted pupils -- visible -- the inside of each of that pupil -- diffraction gratings B and A -- minding -- too -- f" -- supposing two or more shifted fourier diffraction figures appear, amplitude distribution [of a true image] u (x) is expressed with a degree type.

[0025]

u(x) =F [sigmap(f-f') -sigmao (f-f")] -- f'=**SCf"=** (SA-SB-SC) -- here As for the Fourier transform and p (f), a pupil function and o (f) express [F[ ]] the sum to the order of diffraction from which a real space coordinate differs from f in a mask fourier diffraction figure and x, and sin (sine) of the angle of diffraction of diffraction gratings A, B, and C and sigma differ in a spatial-frequency coordinate, and SA, SB and SC. Therefore, if SA=SB+SC, the term which is set to f"=0 and set [as opposed to / both / both f'=**SC(s)] to f"=0 can be acquired. That is, one spectrum o (f) can be seen through two pupils p (f**SC). furthermore -- in order to obtain the image to a same-on mask point at Point P -- the distance between a mask side and diffraction gratings A and B and the distance between a diffraction grating C and the ideal image surface, and Each ZA, ZB, and ZC -- SAand(ZB-ZA) =SC- (ZB+ZC) -- then, it is good.

[0026] When the upper conditions are applied to the optical system of reduction percentage M:1 and the image side numerical aperture NA under paraxial approximation, it turns out that what is necessary is just to set up the distance ZA and ZB between the periods PA, PB, and PC of diffraction gratings A, B, and C, a mask side, and diffraction gratings A and B, and the distance ZC between a diffraction grating C and the ideal image surface almost as follows.

[0027] In order to acquire sufficient improvement effectiveness in resolution by this invention to a 1/PA=1/PB-1/(M-PC) (ZB-ZA)/PA=(ZB/M+M-ZC)/PC pan, considering as lambda/NA<=PC <=root2 and lambda/NA is desirable.

[0028] As for diffraction gratings A and B, it is desirable that it is a phase grating. When diffraction gratings A and B penetrate not a perfect phase grating but zero-order light, effectiveness, such as optical system and oblique incidence optical system, laps with the effectiveness of this approach conventionally which is inferior to definition from this approach. For this reason, there is a possibility that definition may deteriorate. On the other hand, even if a diffraction grating C is a phase modulation grid and it is an amplitude intensity modulation grid, it is not cared about. If the period of a diffraction grating C is quite small and the silicon oxide of a refractive index 1.5 is considered, the cross-section aspect ratio of a grid pattern will become about about one. In this case, it needs to be cautious of the scattering effect of the light in a pattern cross section. In the case of the diffraction grating which consists of a protection-from-light pattern, since thickness of a light-shielding film is made quite thinly, the effect of dispersion can be reduced. However, the direction which uses a phase modulation grid can make an exposure field large so that it may state later.

[0029] If a refractive index n fills the substrate side of a diffraction grating B with a larger liquid than 1 etc., sin will turn into1/n of the wavelength of this field, and an angle of diffraction. Then, if the period of a diffraction grating B is further made fine and an angle of diffraction is made equal to the case where a liquid is not filled, since only wavelength is set to 1/n, resolution will also improve to 1/n. Although the diffracted light with a more big angle of diffraction needs to increase the appearance mask lighting angle which can pass a pupil in a mask side, it becomes impossible in this case, for the diffracted light with a small angle of diffraction to pass a pupil at this time. Then, it is

desirable to increase the path of a pupil according to this. This can also be put in another way as follows. When the refractive index between a diffraction grating B and a substrate is 1, the improvement in resolution is not obtained at all as for 0.5 or more in NA of projection optics used by this invention. sintheta> The angle of diffraction over the beam of light which carries out incidence to the diffraction grating B of periodic lambda/NA at an angle of [theta] 0.5 is for becoming 90 degrees or more, localizing on a diffraction-grating front face as an evanescent wave, and not getting across to a wafer. On the other hand, if the refractive index between a diffraction grating B and a substrate is set to n, angle-of-diffraction theta' of the light which carried out incidence at an angle of sin theta=NA to the diffraction grating B (it must be periodic lambda/NA in order for the zero-order light which passed through the edge of a pupil to carry out vertical incidence to a wafer) will become sintheta'=(lambda/PB+sintheta)/n=2 NA/n, and the conditions for being theta'<90 degree will be set to NA<n/2. That is, this invention is effectively applicable to the optical system of maximum NA=n / 2. Although immersion optical system generally needs a special optical design, when it applies to this invention as mentioned above, a special lens is not needed at all. Therefore, if between a diffraction grating B and substrates is filled with water (refractive index 1.3 [about]) and is exposed using an about 0.6 NA [which is usually used in the semi-conductor process] projection lens, effectiveness equivalent to having set NA to 1.2 substantially will be acquired. In this case, if a phase shift mask is used, the resolution of 0.1 micrometers or less will be obtained also on the wavelength (365nm) of i line of a mercury lamp. In addition, by this approach, since the incident angle of light in which it interferes near the wafer is very large, it depends for the image formation engine performance in the polarization condition of light strongly. Generally, the light in which an electric field vector has a polarization condition perpendicular to the plane of incidence of light is more desirable when forming the image of high contrast.

[0030] All the above arguments need to assume paraxial approximation, need to set the refractive index of the substrate of a diffraction grating to 1, and need to take into consideration strictly in fact the effectiveness of the refractive index of the substrate of a diffraction grating, and the effect of the aberration produced by the diffraction grating. For this reason, the installation location of each diffraction grating etc. may be changed a little. It cannot be overemphasized that it is desirable to make it in agreement in sufficient precision as for the periodic direction of the pattern of two or more diffraction gratings.

[0031] Next, four points are described about the point which it should be careful of in this invention.

[0032] Generally an exposure field is conventionally restricted to the 1st compared with the exposing method by this optical system. Two beams of light cross also in the point Q on the image surface, and Q', it interferes mutually, and an image is formed so that drawing 1 may show. This image is an image of the false produced in the location which should be formed essentially, and out of which it does not come, and, generally is not desirable. In order to avoid this, it is desirable to form the protection-from-light mask 52 in right above [of the image surface 51] (between a wafer and diffraction gratings C), and to intercept the image of these falses, as shown in drawing 5 a. A diffraction grating C and the protection-from-light mask 52 can be formed in both sides of the same quartz substrate 53 as shown in drawing. (You may form on a separate substrate.) preparing similarly this, simultaneously the masking blade which shades the above-mentioned protection-from-light mask and a field [**** / almost] in right above [of a mask], or directly under again etc. -- carrying out -- a mask lighting field -- the above -- restricting to a field [****] is desirable. The exposure field which can be imprinted by one exposure is a field equivalent to the distance (about 2 and NA-ZB) between a true image (P points) and a fake image (Q points), repeats the twice of the above-mentioned distance as a period, and appears. Therefore, when narrower than the area which wants to expose the field which can be exposed, the thing which were shown in drawing 5 b and for which an exposure field is scanned on a wafer is [like] desirable. Under the present circumstances, if the reduction percentage of optical system is M:1, it cannot be overemphasized that it is desirable to also set strictly the ratio of mask scan speed and wafer scan speed to M:1. About the approach of carrying out the synchronous scan of these exposure field on a mask and a wafer, the approach used with the existing aligner can be used as it is. On the other hand, when larger than the area which wants to expose the field which can be exposed (i.e., when the distance between a true image and a fake image covers the chip which is one piece), it can expose, without scanning. The width of face of one

exposure field increases, so that exposure area size is decided by the installation location of a diffraction grating B and a diffraction grating B is separated from the image surface. However, since the width of face of the field which cannot be imprinted to coincidence also increases, both rate does not change as [about 1:1]. In order to eliminate the effect of a fake image, as for the width of face W of an exposure-on wafer field, considering as W<=NA-ZB is desirable. Moreover, when an amplitude intensity modulation grid is used for a diffraction grating B, in order that the zero-order diffracted light of a grid may form the image of another false in the midpoint of a true image and a fake image, when an exposure field is a phase grating, it becomes half mostly.

[0033] Generally by this approach, exposure reinforcement falls to the 2nd. Only the light of the specific order of diffraction is used for the beam of light which carries out image formation on a wafer by this approach among the beams of light diffracted by the diffraction grating inserted into optical system. Therefore, the optical reinforcement which contributes to exposure whenever it passes a diffraction grating will fall. Moreover, having restricted the exposure field on a mask and a wafer, as stated in the top also causes a throughput fall. For this reason, it is desirable to cope with it using resist ingredients, such as a chemistry multiplier system resist with high sensibility which uses the light source with fully strong reinforcement by this approach, etc.

[0034] As pre- explanation showed [3rd], in addition to the desirable diffraction figure of f''=0, on a pupil, the Fourier transform image which shifted only f''=**2 (SA+SB) arises. This means that the high order spectrum of a mask pattern laps with a low spatial-frequency field substantially, and, generally is not desirable. In order to avoid this in the optical system of drawing 1 , it is PA<=1/(1-2 and NA/M).

Then, it is good. In this case, it is because the diffracted light (equivalent to the dotted line emitted out of [A1] drawing 1) of the +primary direction by the diffraction grating A to the diffracted light (inside R1 of drawing 1) diffracted by angle-of-diffraction 2 and NA/M with the mask cannot exist.

[0035] By the optical system of this invention, it needs to be [4th] cautious of the aberration accompanying diffraction-grating installation. The aberration generated by the diffraction grating is explained using drawing 6 . The beam of light after mask passage assumes that it is in a field including the periodic direction of an optical axis and a diffraction grating (for example, a 1-dimensional pattern and coherent illumination). In order for the optical system of drawing 6 a to be non-aberration, the difference of each optical path length of OX1X2X3I, OY1Y2Y3I, and OZ1Z2Z3I must be 0. However, if an optical-path-length difference is among these, this will serve as aberration. If it assumes that projection optics is the ideal optical system of aberration 0, the difference of OX1X2+X3I, OY1Y2+Y3I, and OZ1Z2+Z3I will turn into aberration from X2X3=Y2Y3=Z2Z3 here. If the wave aberration of an optical path which results in OZ1Z2Z3I from OX1X2X3I which crosses the diameter of a pupil is plotted to the pupil radius coordinate s standardized on the basis of OY1Y2Y3I, it will become like the continuous line of drawing 6 b. It turns out that aberration w+ (s) to the beam of light which has the include angle of + to a mask passage glory shaft generally becomes unsymmetrical on a pupil. Aberration w-(s) to the beam of light which has the include angle of - to an optical axis similarly becomes the symmetry from the symmetric property of optical system considering w+ (s) and a pupil as a core. In this invention, since it is necessary to make the light diffracted in the direction of +, and the light diffracted in the direction of - interfere in coincidence on a wafer, it is necessary to amend the aberration to both to coincidence. However, since the pupil top aberration over the light diffracted in the direction of + and the direction of - is not in agreement so that drawing 6 b may show, it becomes difficult theoretically to amend these by projection optics to coincidence. Therefore, as for such aberration, it is desirable to amend between a mask and projection optics or between a wafer and a substrate. Generally this can be performed by the following approaches.

[0036] If w+ (s) and w-(s) is equal, it is possible to amend this by projection optics. then -- delta -- w -- (-- s --) -- = -- {-- w -- + -- (-- s --) --} - {-- w - (-- s --) --} -- a pupil top (with drawing 6 - the range of 1<=s<=1) -- wavelength -- comparing -- the amount delta small enough -- stopping -- ****ing . On the other hand, deltaw** (s) is expressed as a function of the parameters xi (i= 1, 2, --), such as relative-position relation between the installation location of each diffraction grating, the thickness of the substrate supporting a period and a diffraction grating, a refractive index and a substrate, and a diffraction grating. Then, the range of the problem is -1<=s<=1, and it results in

calculating xi which fills deltaw(s, xi) <delta. An example describes the example of actual optimization. Anyway, it can do in this way and a symmetrical form, then this symmetrical can be amended for the aberration over the beam of light which has the include angle of ** to a mask passage glory shaft in projection optics on a pupil. Furthermore, it is more desirable if the aberration itself can fully be controlled by the approach described in the top.

[0037] As mentioned above, since it was easy, the 1-dimensional pattern was assumed as a mask pattern, but when a two-dimensional pattern exists in fact or partial coherent illumination is used, the beam of light after mask passage is not settled in a field including the periodic direction of an optical axis and a diffraction grating, but tends toward various points on a pupil. In this case, what is necessary is to consider function deltaw(s, t) ={w+(s, t)}-{w-(s, t)} of the two-dimensional coordinate on a pupil (s, t), and just to calculate as deltaw, xi which fills deltaw(s, t, xi) <delta within a pupil surface. This means making w** (s, t) into the most symmetrical possible form to s= 0 on a pupil.

[0038] Furthermore, in order to acquire the effectiveness of this invention to all directions, it is possible to use each diffraction grating as a two-dimensional diffraction grating, as shown in drawing 7 a and b. In this case, the form of the pupil on appearance serves as symmetry 4 times. However, except for the case where NA of optical system is small, it is a little difficult to carry out aberration amendment on a pupil to 2 sets of perpendicular pupils according to the situation described in the top at coincidence mutually. For this reason, it is a little difficult to acquire the effectiveness of this invention equally to all directions on a mask, and it is more realistic to use a 1-dimensional diffraction grating like drawing 8 . Drawing 8 a, b, and c sees with three typical diffraction gratings, and is the upper pupil configurations. In drawing 8 a, substantial NA increases about twice to the pattern of x directions, but it decreases to the pattern of the direction of y. In drawing 8 b, to the pattern of x directions, substantial NA becomes root2 twice and is set to 1/root2 to the pattern of the direction of y. As for NA, in drawing 8 c, x and y both directions become root2 twice, but it is thought that it depends for the image formation engine performance [/ in addition to x and the direction of y] in the direction of a pattern remarkably. It is desirable to impose the limit by the direction on the layout rule of a pattern etc. on a mask in any case.

[0039] In order to abolish the pattern direction dependency of the image formation engine performance, the conditions of drawing 8 a, b, and c may be rotated 90 degrees respectively, for example, and multiplex exposure may be performed. When this is especially applied to drawing 8 c, an image equivalent to x and y both directions having doubled NA root2, without controlling pattern direction dependency [/ in addition to x and the direction of y], and sacrificing image contrast can be obtained. However, when rotating a diffraction grating 90 degrees, an aberration property is also rotated 90 degrees. Then, it is desirable to cope with to perform aberration amendment using a pupil filter and to rotate this 90 degrees with a diffraction grating etc. In addition, when aberration control is difficult, you may carry out preparing a slit filter in a pupil if needed etc.

[0040] As shown in drawing 3 , when perfect coherent illumination of the periodic mold phase shift mask is carried out, the optical path of primary [**] light in which it interferes near the wafer is always symmetrical to an optical axis, and each optical path length is equal. Therefore, even if aberration amendment of the optical system is not carried out, detailed pattern formation is possible. That is, when using a periodic mold phase shift mask under perfect coherent illumination, a two-dimensional diffraction grating as shown in drawing 7 is usable, it does not depend in the direction of a pattern, but the effectiveness of a phase shift mask can be demonstrated to the maximum extent. What is necessary is to expose only a detailed period pattern by the above-mentioned approach, and just to expose other parts by the exposing method conventionally after that, in imprinting the mask pattern with which various patterns are intermingled.

[0041] Moreover, generally the above-mentioned aberration increases rapidly with the value of NA. For this reason, in about 0.1 to 0.2-NA optical system, it does not become a problem comparatively. Therefore, when applying to the aligner for large areas of low NA and a low scale factor, the soft-X-ray contraction projection aligner of a reflective mold, etc., various constraint which was described in the top is mitigated.

[0042] As mentioned above, this invention passes a pupil for right-and-left one side of the fourier diffraction figure centering on a zero-order diffracted-light line separately respectively, and it can be

said that it is what compounds this by the image side. Although it is already applied to the optical microscope as this view itself is discussed by the above-mentioned reference, the configuration of optical system realizable on contraction projection optics was not devised in this until now. This invention is exactly what realized this skillfully in the reduced-projection-exposure system. That is, the optical system of drawing 1 prepares a diffraction grating between projection optics and a wafer, and it constitutes optical system so that an image faithful to the original mask pattern may be reproduced as a result of wafer side interference, while it enlarges the incident angle of the light beam which carries out incidence to a wafer side. This invention is applicable to various projection optics, such as dioptric system, catoptric system and these combination, contraction optical system, and actual size optical system. Also as the exposure approach in the case of exposing a mask pattern to up to a wafer using such optical system, it is applicable to both a package imprint, a scanning method step-and-repeat one a step a scan, etc. Moreover, this invention is purely based on geometrical optics-effectiveness so that more clearly than the above explanation. Therefore, the trouble which originates for [as / in the approach using the above-mentioned Moire fringe] EBANESSENTO Mitsutoshi is not produced. Moreover, since it can detach from a wafer, it can install and there is moreover also no need, such as a synchronous scan, a diffraction grating is easily realizable far.

[0043]

[Example]

(Example 1) Based on this invention, as the scanning mold KrF excimer laser projection aligner of NA=0.45, the light source wavelength of lambda= 248nm, and reduction percentage 4:1 was typically shown in drawing 9 , it converted. That is, the transparence quartz plate 103 which has a phase grating pattern was inserted in both sides between the masks 101 and projection optics 102 which were installed on the mask stage 100. Moreover, between the wafers 105 and projection optics 102 which were installed on the wafer stage (sample base) 104, the protection-from-light pattern and the transparence quartz plate 106 which already has a phase grating pattern on one side were inserted in one side so that a protection-from-light pattern side might meet a wafer. The protection-from-light pattern used with a width-of-face period [1mm period of 300 micrometers] Cr pattern, and the phase grating pattern as Si oxide-film pattern of periodic = lambda/NA. It is 4 times [by the side of a wafer] the period of the phase grating pattern on the mask side transparence quartz plate 103 of this. Si oxide-film thickness was set up so that the phase of the light which penetrated the film's existence section and the part not existing might shift 180 degrees. These patterns were formed like the so-called production process of a chromium loess phase shift mask using EB lithography. Moreover, the transparence quartz plate 108 which has width of face of 1.2mm and a periodic =4mm protection-from-light pattern was formed in the illumination-light study system 107 side of a mask. The protection-from-light field of the above-mentioned protection-from-light pattern was set up so that it might become a protection-from-light pattern on the wafer side transparence quartz plate 106, and conjugate.

[0044] Thickness, an installation location, etc. of the period of the phase grating of transparence quartz plate 103 both sides and each transparence quartz plate were optimized using the ray-tracing program optimization function so that the aberration on the projection optics pupil in the semantics stated to the term of an operation might serve as axial symmetry. Furthermore, the aberration amendment filter 109 was inserted in the pupil posion of projection optics for aberration amendment symmetrical with the above-mentioned shaft. Here, the aberration amendment filter 109 amends the astigmatism of a direction mainly perpendicular to the periodic direction of the above-mentioned diffraction grating. In addition, each of transparence quartz plates which have these diffraction gratings etc., and aberration amendment filters is exchangeable, and it enabled it to set them up for whether being Sumiya at a position. Moreover, in order to position a transparence quartz plate correctly, the electrode holder (not shown) of each quartz substrate has a jogging device (not shown), can measure the location of each quartz substrate, and can set this as a desired location. Furthermore, by acting as the monitor of the image by the automatic focus monitor (not shown) which prepared on the wafer stage 104, it also made it possible to feed back a monitor result and to adjust the location of each quartz substrate so that the optimal image formation property might be acquired on the image surface. In addition, aberration amendment may be beforehand performed for the projection optics

itself to the above-mentioned diffraction grating, and an aberration amendment filter is unnecessary in this case. Exposure was performed carrying out the synchronous scan of a mask and the wafer. A stage control system 110 carries out the synchronous scan of a mask stage 100 and the wafer stage 104 with the velocity ratio of 4:1 respectively.

[0045] The mask which has the pattern of various dimensions containing a periodic mold phase shift pattern was imprinted to up to the chemistry multiplier system positive resist using the above-mentioned aligner. As a result of performing a development predetermined [after exposure] and observing under a scanning electron ray microscope, the resist pattern with a dimension of 90nm (period of 180nm) has been formed with the periodic mold phase shift mask to the periodic direction (x directions) of the above-mentioned phase grating. On the other hand, the resolution of a direction (the direction of y) perpendicular to the above-mentioned direction was dimension extent of 140nm (period of 280nm) using the phase shift mask. Then, when the phase grating of the three above-mentioned sheets and the aberration amendment filter were rotated 90 degrees, the same mask was exposed next and the resist pattern was formed, the resolution to x directions and the direction of y was reversed.

[0046] In addition, although, as for the upper example, a period, an installation location, etc. of the class of the class of optical system, NA, light source wavelength, reduction percentage, a resist, and mask pattern, a dimension and a diffraction grating, and a protection-from-light pattern are limited extremely, these various conditions can be variously changed within limits which are not contrary to the main point of this invention.

[0047] (Example 2) Next, the example which optimized optical system is shown so that the effect of the aberration accompanying diffraction-grating installation may serve as min. In the optical system of drawing 10 , the mask side of projection optics where mask side [where O and I introduced the diffraction grating / of optical system], image surface, sigma, and sigma' does not introduce a diffraction grating, the image surface, and hi (i=1-6) show the distance in drawing. The protection-from-light pattern of diffraction gratings A, B, and C and wafer right above was formed in both sides of a transparence quartz substrate like the example 1. At this time, transverse aberration w** (s) to the beam of light which has the include angle of ** to an optical axis after mask passage is expressed as follows as a function of the standardization pupil radius coordinate s.

[0048]

w**(s) =wu** (s) +ws** (s) wu**(s) =C1h1+C2(s1) h2+C5h5 -- +C6h6 ws**(s) =C3h3 -- +C4h4 C1=tan[(second**s0) /M]/M and C2=tan[**(s1/n)-(second**s0)/(nM)]/M -- C3=tan[s/M]/M and C4= -- tan (s) C5=tan[(second**s0) /n] C6=tan (second**s0) -- here, wu expresses an unsymmetrical component and a component with symmetrical ws to s= 0 on a pupil. However, they are s0=NA and s1= lambda/PA. When s0 (NA), the contraction scale factor M, and the refractive index n of a transparence quartz substrate are made into the value of a system proper, an upper type contains seven optimization parameters, and hi (i=1-6) and s1. Then, these values were optimized wu** and by imposing seven constraints that aberration should be made min to ws** (s) (s). An example of an optimization result to some NA(s) is shown in Table 1. However, aberration was expressed with the wave aberration which makes h5/lambda a unit.

[0049]

[Table 1]

表1

NA	0.1	0.2	0.3	0.4
h_1/h_5	17.352	16.167	14.263	11.343
h_2/h_5	0.529	0.995	1.343	1.507
h_3/h_5	24.014	22.800	20.137	14.819
h_4/h_5	0.368	0.485	0.652	0.920
h_6/h_5	0.01	0.01	0.01	0.01
s_1	1.225	1.259	1.300	1.349
$w_{max}(s)$	$5x10^{-9}$	$3x10^{-7}$	$4x10^{-6}$	$5x10^{-6}$
$w^U_{max}(s)$	$1x10^{-12}$	$1x10^{-9}$	$2x10^{-7}$	$1x10^{-5}$

$$w^U_{max}(s) = \max[w+(s) - w-(s)]$$
$$s1 = n\lambda/PA$$

[0050] As shown in a table, it was possible to fully have suppressed aberration also in NA=0.4. Same optimization can be performed to various arrangement, when diffraction gratings A and B are respectively formed on another transparence substrate. Furthermore, still severer aberration conditions can be satisfied by increasing the parameter of optimization by introducing a new transparence substrate and a new diffraction grating.
[0051] (Example 3) Next, the example which created DRAM of 0.1-micrometer design Ruhr is described using the aligner shown in the example 1. Drawing 11 shows the making process of the above-mentioned device focusing on an exposure process.
[0052] First, isolation 202 and the gate 203 were formed on the Si substrate 201 in which the well etc. was formed (not shown) (drawing 11 a). Isolation and a gate pattern were exposed with the aligner shown in the example 1 using the periodic mold phase shift mask. Here, since it was predicted that the part into which a pattern configuration is distorted in the periphery of a periodic pattern by simulation arises, the mask for removing this garbage was prepared. After piling up and exposing the above-mentioned mask using an aligner to the same resist film as what performed the above-mentioned exposure conventionally, negatives were developed, and the part which is not desirable was removed on the circuit engine performance. In addition, you may cope with it by ignoring in circuit, without removing the above-mentioned garbage.
[0053] Next, the capacitor 204 and the contact hole 205 were formed (drawing 11 b). The electron ray direct writing method was used for pattern exposure of a contact hole. Next, the 1st-layer wiring 206, a through hole (not shown), and the 2nd-layer wiring 207 were formed (drawing 11 c). The 1st-layer wiring (0.1micromL/S) was exposed using the aligner shown in the periodic mold phase shift mask and the example 1. However, it changed into what showed the direction and dimension of each diffraction grating to drawing 9 c here, this was rotated further 90 degrees, and multiplex exposure was performed. Coincidence was made to also rotate the aberration amendment filter 109 90 degrees with a diffraction grating at this time. 0.1micromL/S has been formed without direction dependency to wiring prolonged in both directions in every direction by this. Formation of a through hole used the electron ray direct writing method like the contact hole. Subsequent multilayer-interconnection patterns and final passivation patterns are designed in 0.2-micrometer Ruhr, and were formed by the usual KrF excimer laser projection exposing method do not use this invention. In addition, it is not caught by what was used in the above-mentioned example about the structure of a device, an ingredient, etc., but can change.
[0054] (Example 4) Next, the example which applied this invention to manufacture of distribution feedback mold (DFB) laser is described as another example of this invention. What converted the ArF excimer laser contraction projection aligner of NA0.5 like the example 1 was used for the aligner. In the making process of the conventional quarter-wave length shift DFB laser, the diffraction grating with a period of 140nm currently formed using the electron-beam-lithography

method etc. was formed using the periodic mold phase shift mask and the above-mentioned aligner. It became possible to manufacture more the DFB laser which has by this the engine performance almost equivalent to what was produced using the electron-beam-lithography method etc. for a short period of time.

[0055]

[Effect of the Invention] As mentioned above, when according to this invention light is irradiated through an illumination-light study system at a mask, image formation of the mask pattern is carried out to up to a substrate according to projection optics and a pattern is formed, While preparing a diffraction grating in the above-mentioned substrate and parallel between the above-mentioned substrate and the above-mentioned projection optics So that the image of a mask pattern may be reproduced by interference of the light diffracted by the above-mentioned diffraction grating near the substrate side By establishing a diffraction grating or image formation optical system between projection optics and a mask or between a mask and an illumination-light study system, formation of the detailed pattern conventionally beyond the resolution limit of an aligner is attained. Specifically, effectiveness almost equivalent to having a maximum of doubled the NA substantially is acquired, without changing NA of projection optics. Without changing the fundamental configuration of the optical system of an aligner greatly thereby conventionally, the big exposure field and high resolution are acquired and manufacture of LSI of a dimension the class of 0.1 micrometers is attained using the contraction projection optical lithography suitable for mass production method.

[0056]

[Translation done.]

DESCRIPTION OF DRAWINGS

[Brief Description of the Drawings]
[Drawing 1] It is the mimetic diagram showing geometrically the principle of the image formation of 1 optical system by this invention.
[Drawing 2] It is the mimetic diagram showing the principle of the image formation by the exposing method conventionally [various].
[Drawing 3] It is the mimetic diagram showing the principle of the image formation at the time of applying a phase shift mask or slanting illumination to 1 optical system by this invention.
[Drawing 4] It is the mimetic diagram showing the principle of the image formation of 1 optical system by this invention in diffracted-light study.
[Drawing 5] It is the mimetic diagram showing a part of 1 optical system and an example of the exposure approach by this invention.
[Drawing 6] It is the mimetic diagram showing the property of 1 optical system by this invention.
[Drawing 7] It is the mimetic diagram showing the optic used by this invention, and the effectiveness acquired by that cause.
[Drawing 8] It is the mimetic diagram showing the optic used by this invention, and the effectiveness acquired by that cause.
[Drawing 9] It is the mimetic diagram showing the configuration of the aligner by one example of this invention.
[Drawing 10] It is drawing showing the property of another example of this invention.
[Drawing 11] It is the mimetic diagram showing the device making process by another example of this invention.
[Description of Notations]
1 [-- 5 A wafer, 20 / -- It extracts.] -- A mask, 2 -- Projection optics, 3 -- A pupil, 4 6 29 [-- Zero-order diffracted light,] -- An optical axis, A, B, C -- A diffraction grating, R -- Light, R0, R0' R1, R+, R1" -- The +primary diffracted light, R1', R --- -primary diffracted light, A0, A1 -- The point on a diffraction grating A, B0, B1 -- The point on a diffraction grating B, C0 and C1, C1' -- The point on a diffraction grating C, Q, P, Q' [-- Projection optics,] -- The point on the image surface, 21 -- The conventional transparency mold mask, 22 -- Light, 23 24 [-- Zero-order light of the mask diffracted light,] -- A pupil, 25 -- The image surface, 26 -- A periodic mold phase shift mask, 27 28--+primary light, 51 -- The image surface, 52 -- A protection-from-light mask, 53 -- Quartz substrate, O -- The point on a mask, X1, Y1, Z1 -- The point on a diffraction grating A, X2, Y2, Z2 -- The point on a diffraction grating B, X3, Y3, Z3 -- The point on a diffraction grating C, I -- The point on the image surface, 100 -- Mask stage, 101 [-- Wafer stage (sample base),] -- A mask, 102 -- Projection optics, 103 -- A transparence quartz plate, 104 105 [-- Transparence quartz plate,] -- A wafer, 106 -- A transparence quartz plate, 107 -- An illumination-light study system, 108 109 [-- Isolation, 203 / -- The gate, 204 / -- A capacitor, 205 / -- A contact hole, 206 / -- The 1st-layer wiring, 207 / -- The 2nd-layer wiring.] -- An aberration amendment filter, 110 -- A stage control system, 201 -- Si substrate, 202

[Translation done.]

* NOTICES *

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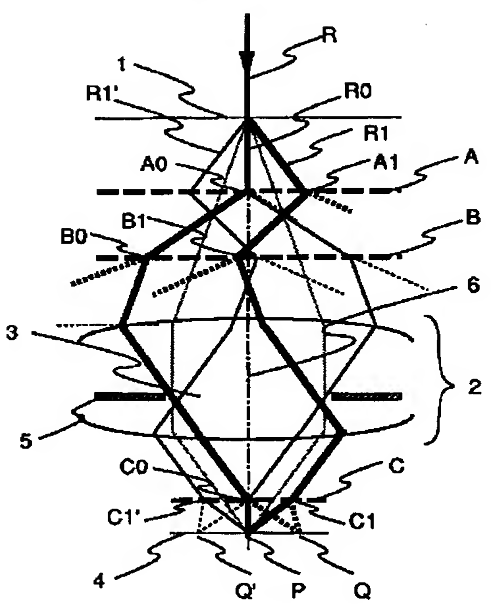
1.This document has been translated by computer. So the translation may not reflect the original precisely.
2.**** shows the word which can not be translated.
3.In the drawings, any words are not translated.

DRAWINGS

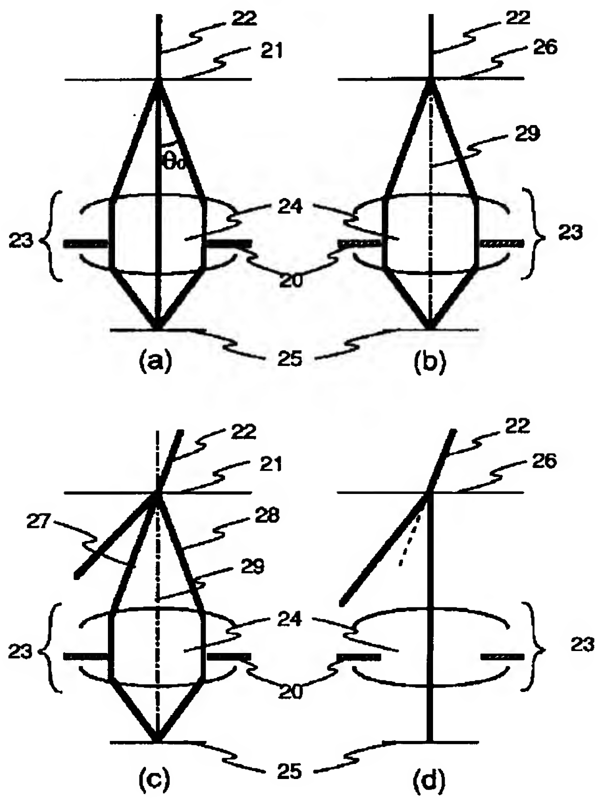
[Drawing 1]

図1



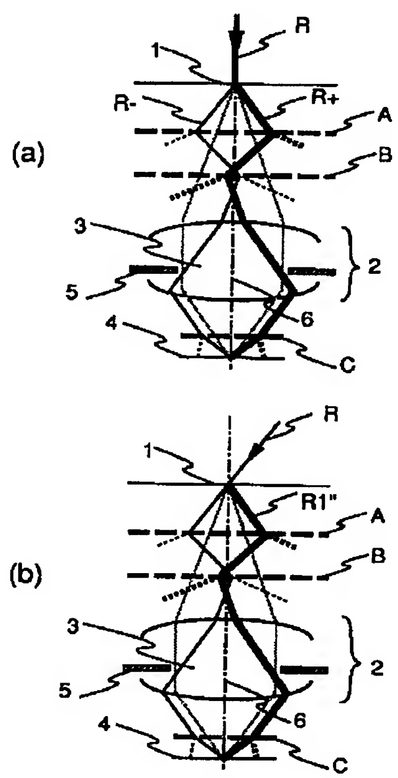
[Drawing 2]

図 2



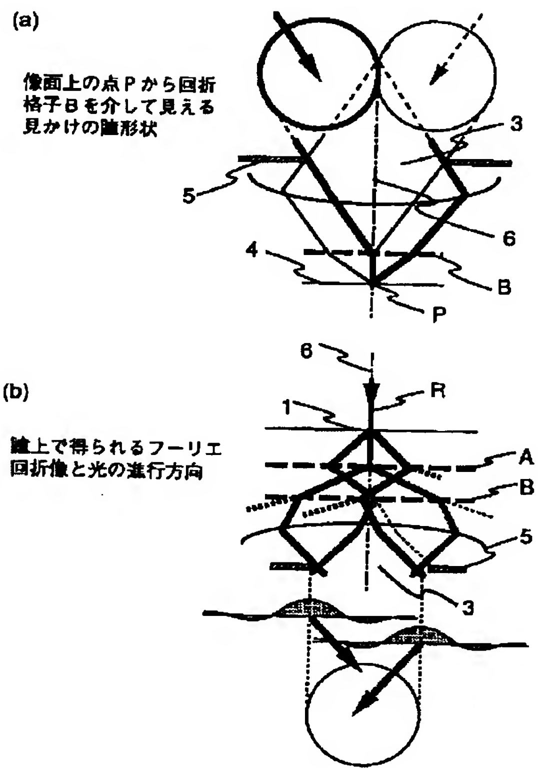
[Drawing 3]

図 3



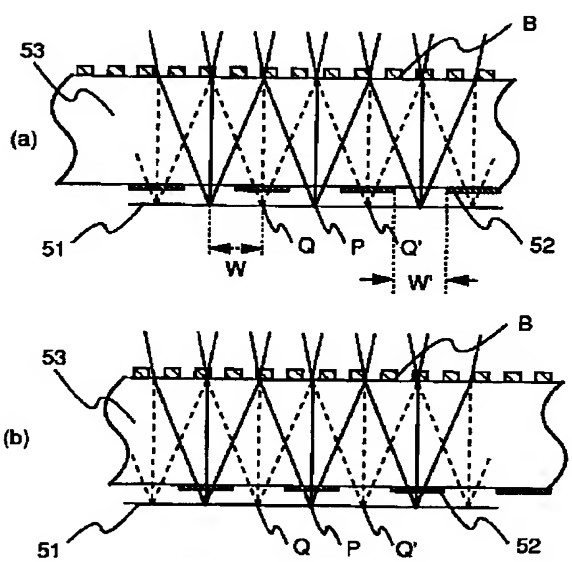
[Drawing 4]

図4



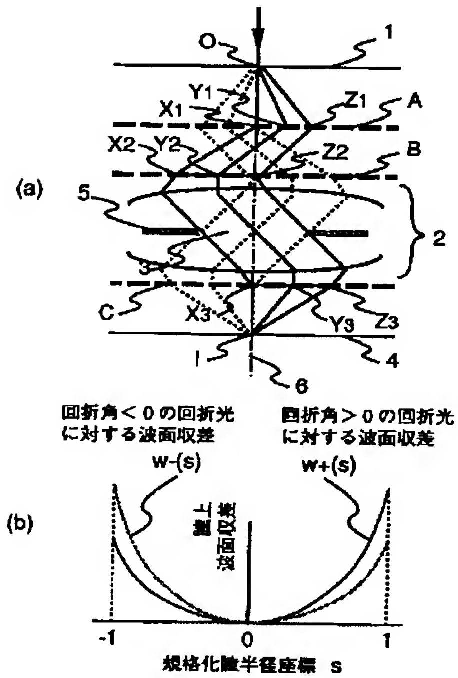
[Drawing 5]

図5



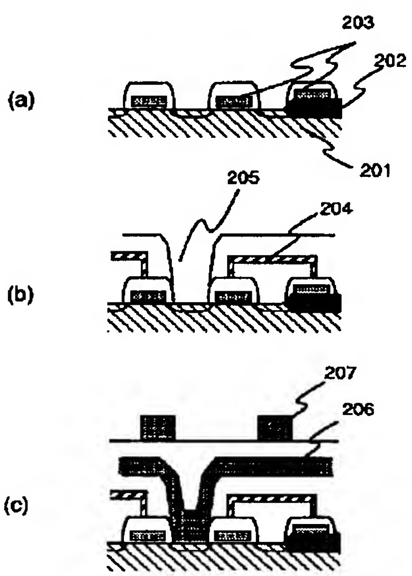
[Drawing 6]

図6



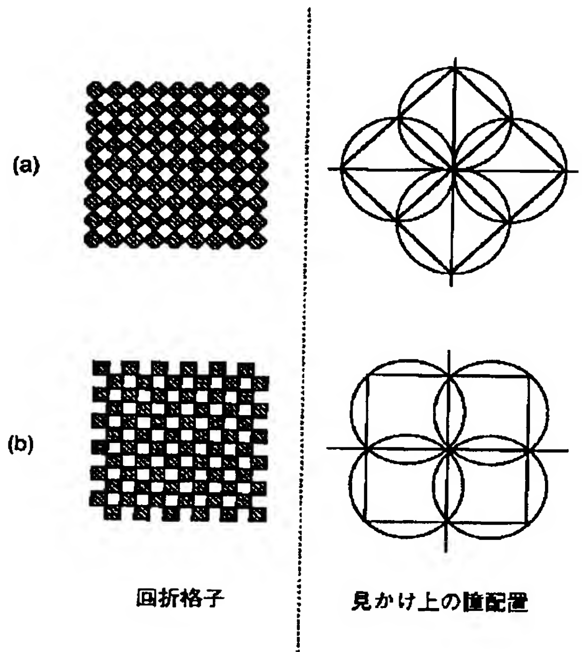
[Drawing 11]

図１１



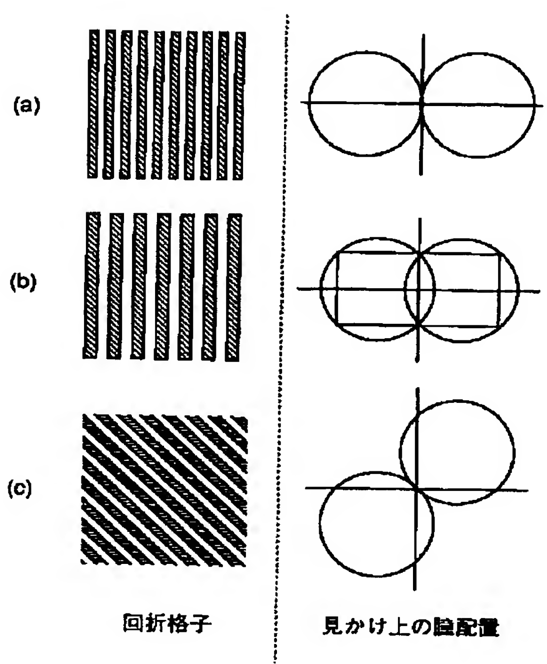
[Drawing 7]

図7



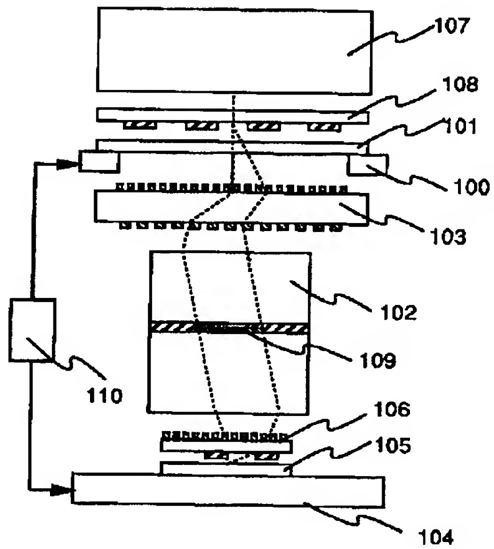
[Drawing 8]

図8



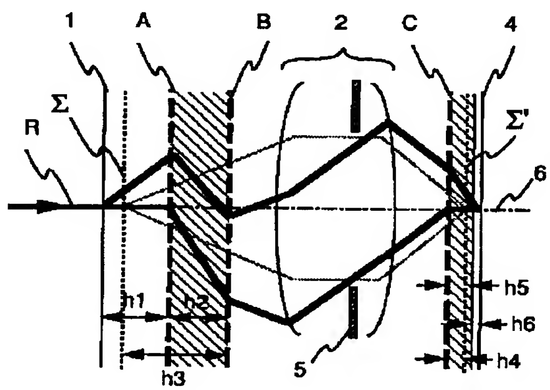
[Drawing 9]

図9



[Drawing 10]

図１０



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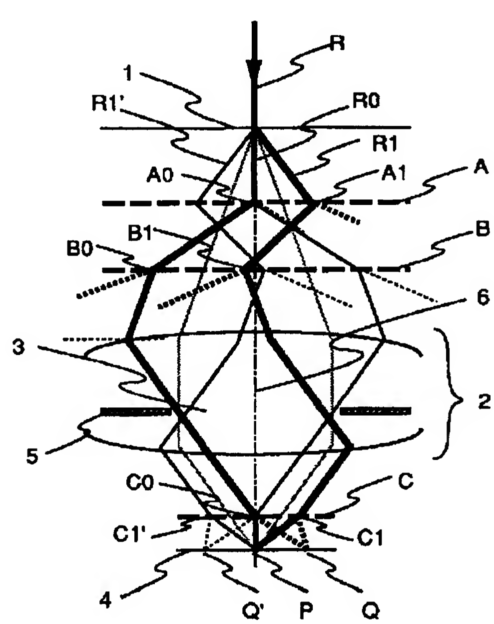
(54)【発明の名称】　投影露光方法及び露光装置

(57)【要約】

【構成】　マスク１を投影光学系２により基板４上へ投影露光する際、マスク１と投影光学系２の間に２枚の回折格子（Ａ，Ｂ）を、投影光学系と基板の間に１枚の回折格子Ｃを設け、これにより回折された光の干渉により基板面近傍でマスクパターンの像が再生されるようにした。

【効果】　従来露光装置の空間部分に回折格子を挿入するだけで、光学系のＮＡを実質的に最大２倍にした効果が得られる。このため、大きな露光フィールドを持ち大量生産に適した縮小投影光リソグラフィを用いて、寸法０．１μｍクラスのＬＳＩの製造が可能となる。

図１



【特許請求の範囲】
【請求項１】マスクを準備する工程と、光源からの光を上記マスクに照射する工程と、
上記マスクのパターンを回折する工程と、
該回折した光を投影光学系を通して回折し試料上に上記マスクパターンを再生し露光する工程から成ることを特徴とする投影露光方法。
【請求項２】上記回折する工程として２回回折することを特徴とする請求項１記載の投影露光方法。
【請求項３】光源と、
該光源からの光でマスク上のパターンを照射し、該マスクからの光を回折する第１と第２の回折手段と、
回折した光を試料上に投影する投影光学系と、
該投影光学系からの光を回折する第３の回折手段と、
該第３の回折手段の下に配置された試料を載置する試料台からなることを特徴とする投影露光装置。
【請求項４】上記第１と第２の回折手段は位相格子であることを特徴とする請求項３記載の投影露光装置。
【請求項５】光源を発した波長λの光を照明光学系を介してマスクに照射し、上記マスク上のパターンを開口数ＮＡ、縮小率Ｍ：１の投影光学系により基板上へ結像させることにより上記基板上にパターンを形成する方法において、上記基板と上記投影光学系の間に上記基板と平行な第１の回折格子を有し、前記第１の回折格子により回折された光の干渉により基板面近傍でマスクパターンの像が再生されるように、上記マスクと上記照明光学系の間に、上記マスクと平行に、上記マスク側から順に第２の回折格子と第３の回折格子の２枚の回折格子を設けることを特徴とする投影露光方法。
【請求項６】前記回折格子を設けた光学系の遮断空間周波数ｆが、前記回折格子を設けない光学系の遮断空間周波数ｆ０より大きく、かつｆ０の２倍以下であることを特徴とする請求項５記載の投影露光方法。
【請求項７】前記第１の回折格子の空間周期Ｐ１は、
λ／（1.42・ＮＡ）≦Ｐ１≦λ／ＮＡ
の範囲にあることを特徴とする請求項５記載の投影露光方法。
【請求項８】上記第１、第２及び第３の回折格子の周期方向は等しく、上記第１の回折格子の空間周期Ｐ１、第２の回折格子の空間周期Ｐ２、第３の回折格子の空間周期Ｐ３は、ほぼ
１／Ｐ３＝１／Ｐ２-１／（Ｍ・Ｐ１）
の関係を満たすことを特徴とする請求項５記載の投影露光方法。
【請求項９】上記第１の回折格子の上記基板表面から光学距離Ｚ１、及び、上記第２、第３の回折格子の上記マスク表面から光学距離Ｚ２、Ｚ３は、ほぼ
（Ｚ３-Ｚ２）／Ｐ２＝（Ｚ３／Ｍ+Ｚ１・Ｍ）／Ｐ１
の関係を満たすことを特徴とする請求項５記載の投影露光方法。
【請求項１０】上記第１の回折格子、上記第２の回折格子、及び上記第３の回折格子の各設置位置、上記第１の回折格子、上記第２の回折格子、及び上記第３の回折格子を設ける各透明基板の膜厚、及び上記第２の回折格子の周期を、前記投影光学系のＮＡ及び縮小倍率、各回折格子と上記基板の位置関係に応じて、上記マスク面と像面の間の収差が最小となるように設定したことを特徴とする請求項５記載の投影露光方法。
【請求項１１】前記第２の回折格子の空間周期Ｐ２は、
Ｐ２≦１／（1-２・ＮＡ／Ｍ）
を満たすことを特徴とする請求項５記載の投影露光方法。
【請求項１２】前記第２及び第３の回折格子は、位相格子であることを特徴とする請求項５記載の投影露光方法。
【請求項１３】前記第１の回折格子は、位相格子であることを特徴とする請求項５記載の投影露光方法。
【請求項１４】前記基板と前記第１の回折格子の間に、前記一方向に対する幅がＺ１・ＮＡ以下で、空間周期がほぼ２・Ｚ１・ＮＡの第１の遮光パターンを設けるとともに、前記マスクの直上又は直下に、マスク上の上記第１の遮光パターンとほぼ共役な領域を遮光する第２の遮光パターンを設けて露光領域を制限するか、又は、上記制限された露光領域を基板上で走査して露光するか、もしくはステップ状に移動しながら露光することを特徴とする請求項５記載の投影露光方法。
【請求項１５】前記回折格子は１次元回折格子であり、前記投影光学系の波面収差が、瞳上での上記回折格子の周期方向と垂直な方向の直径を軸として、線対称となるように収差補正されていることを特徴とする請求項５記載の投影露光方法。
【請求項１６】前記マスクは、周期型位相シフトマスクを含むことを特徴とする請求項５記載の投影露光方法。
【請求項１７】前記マスクは、前記第１の回折格子の周期及び方向に応じて、特定方向に微細なパターンを有することを特徴とする請求項５記載の投影露光方法。
【請求項１８】前記マスクは、前記第１の回折格子の周期及び方向に応じて、パターン形状を補正したことを特徴とする請求項５記載の投影露光方法。
【請求項１９】前記第１の回折格子と前記基板の間を、屈折率ｎが１より大きい液体で満たし、前記投影光学系のＮＡを、
0.5＜ＮＡ＜ｎ／２
の範囲に設定したことを特徴とする請求項５記載の投影露光方法。
【請求項２０】光源を発した波長λの光をマスクステージ上のマスクに照射する照明光学系と上記マスク上のパターンを基板ステージ上の基板表面近傍で結像させる開口数ＮＡ、縮小率Ｍ：１の投影光学系を有する投影露光装置において、上記基板と上記投影光学系の間に上記基

板と平行な第1の空間周期Ｐ１（λ／（1.42・ＮＡ）≦Ｐ１≦λ／ＮＡ）の第1回折格子を有し、上記第1の回折格子により回折された光の干渉により基板面近傍でマスクパターンの像が再生されるように、上記マスクと上記照明光学系の間に、上記マスクと平行に、上記マスク側から順に第2の回折格子と第3の回折格子の2枚の回折格子を有することを特徴とする投影露光装置。

【請求項２１】上記第1、第2及び第3の回折格子の周期方向は等しく、上記第1の回折格子の空間周期Ｐ１、第2の回折格子の空間周期Ｐ２、第3の回折格子の空間周期Ｐ３は、ほぼ

１／Ｐ３＝１／(Ｍ・Ｐ１)＋１／Ｐ２

の関係を満たすことを特徴とする請求項２０記載の投影露光装置。

【請求項２２】上記第1の回折格子、上記第2の回折格子、及び上記第3の回折格子の各設置位置、上記第1の回折格子、上記第2の回折格子、及び上記第3の回折格子を設ける各透明基板の膜厚、及び上記第2の回折格子の周期を、前記投影光学系のＮＡ及び縮小倍率、各回折格子と上記基板の位置関係に応じて、上記マスク面と像面の間の収差が最小となるように設定したことを特徴とする請求項２０記載の投影露光装置。

【請求項２３】前記基板と前記第1の回折格子の間に、前記一方向に対する幅がＺ１・ＮＡ以下で、空間周期がほぼ２・ＮＡ・Ｚ１の遮光パターンを有するか、又は、上記遮光パターンにより制限された露光領域を基板上で走査して露光するか、もしくはステップ状に移動しながら露光する機能を有することを特徴とする請求項２０記載の投影露光装置。

【発明の詳細な説明】

【０００１】

【産業上の利用分野】本発明は、各種固体素子の微細パターンを形成するためのパターン形成方法、及びこれに用いられる投影露光装置に関する。

【０００２】

【従来の技術】ＬＳＩ等の固体素子の集積度及び動作速度を向上するため、回路パターンの微細化が進んでいる。又、レーザー等の光・電子素子や各種の量子効果素子、誘電体・磁性体素子等の特性向上のため、パターンの微細化が望まれている。現在これらのパターン形成には、量産性と解像性能に優れた縮小投影露光法が広く用いられている。この方法の解像限界は露光波長に比例し投影レンズの開口数（ＮＡ）に反比例するため、短波長化と高ＮＡ化により解像限界の向上が行われてきた。

【０００３】又、縮小投影露光法の解像度をさらに向上するための手法として、位相シフト法、変形照明法（斜入射照明法）、瞳フィルター法等、様々な像改良法が適用されている。これらは、従来光学系の性能を理論的な回折限界（遮断空間周波数＝２ＮＡ／λ）ぎりぎりまで有効に使用しようというものである。これら像改良法（しばしば超解像法と呼ばれる）については、例えば、ＵＬＳＩリソグラフィ技術の革新、第１章、第３４頁から第４９頁（サイエンスフォーラム社刊、１９９４年、東京）に論じられている。

【０００４】一方、顕微鏡の解像度を、従来の上記回折限界を越えて向上する方法として、光学系の空間周波数帯域を拡大する方法がいくつか知られている。これら空間周波数帯域拡大法については、例えば、応用物理、第３７巻、第９号、第８５３頁から第８５９頁（１９６８年）に論じられている。このうちの１つの方法は、２つの格子パターンを物体及び像の直上（少なくとも焦点深度内）で互いに共役関係を保ちつつスキャンするもので、物体とその直上の第１格子パターンの重ねあわせによりモアレパターンを形成し、このモアレパターンをレンズ系を通過させ、像側で第２の格子パターンと重ねることにより復調を行なう。モアレパターンは、物体及び第１格子パターンより低い空間周波数を有するため、レンズ系を通過することができる。この方法を縮小投影露光法に適用することが出願されている。一般に、ウエハー直上で格子パターンを機械的にスキャンするのは困難なため、ホトクロミック材料をウエハ上に直接設け、これに干渉縞を重ねてスキャンすることにより、格子として機能させている。

【０００５】

【発明が解決しようとする課題】しかしながら、上記様々な従来技術には次のような課題がある。

【０００６】まず露光光の短波長化は、光学（レンズ）材料の透過率の問題からＡｒＦエキシマレーザ（波長１９３ｎｍ）が限界と考えられる。又、レンズ設計及び製造上の問題から、投影光学系のＮＡは０.６～０.７が限界と考えられる。しかるに、従来露光法の解像限界は一般に０.５λ／ＮＡ、周期型位相シフト法を用いた場合は０.３λ／ＮＡ程度であり、従って、上記短波長化及び高ＮＡ化の限界を用いても、０.１μm以下のパターンは形成は難しい。又、上記周期型位相シフト法ではマスクパターンが制限されるため、より一般的な回路パターンに関して、実際の限界寸法はさらに後退する。又、ＬＳＩの大規模化に伴い露光面積の拡大が要求されているが、投影光学系の露光フィールドの拡大と高ＮＡ化の要求を同時に満足することは極めて困難となっている。

【０００７】一方、従来の回折限界を越えることを目的とする各種空間周波数帯域拡大法は顕微鏡を対象とし、微小な物体を拡大することを目的とする。このため、光リソグラフィで要求される微小な光学像を形成するのには必ずしも適してはいないという問題点があった。例えば、前記モアレパターンを利用する方法では、２つの格子をマスク及びウエハーの直上で互いに共役関係を保ちつつスキャンするための機構又は光学系が著しく複雑となる。レジストの露光が実質的にエバネッセント光で行われるため波長レンジで光が減衰して厚いレジストを露

光するのが困難となる等の問題がある。さらに、ホトクロミックを使用する場合でも適当な材料がない。従って、ＬＳＩの大量生産を考えた場合、必ずしも実用的とはいえないという問題点があった。

【０００８】本発明の目的は、各種固体素子の微細パターンを形成する投影露光法において、その解像度を、従来の回折限界（遮断空間周波数）を越えて向上する方法を提供することにある。具体的には、投影光学系のＮＡを変えることなしに、そのＮＡを実質的に最大２倍にしたのとほぼ同等の効果が得られる新規な投影露光方法と、これを可能とする露光装置を提供することにある。

【０００９】本発明の別の目的は、従来型の露光装置の構成と光学系を大きく変更することなく、これらに多少の改良を加えるだけで解像力向上効果の得ることが可能で、かつ大きな露光フィールドと高い解像力を同時に満足するＬＳＩの大量生産に適した投影露光方法を提供することにある。

【００１０】

【課題を解決するための手段】上記目的は、波長λの光を用いてマスクパターンをの投影光学系（開口数＝ＮＡ、縮小率＝１：Ｍ）により基板上へ結像させてパターンを形成する際、上記基板と上記投影光学系の間に、上記基板と平行に、空間周期Ｐ１（但し、$\lambda/(1.42\cdot NA) \leqq P1 \leqq \lambda/NA$であることが望ましい）の第１の回折格子を設けるとともに、上記第１の回折格子により回折された光の干渉により基板面近傍でマスクパターンの像が再生されるように、前記投影光学系と前記マスクの間に、上記マスクと平行に、上記マスク側から順に第２の回折格子と第３の回折格子の２枚の回折格子を設けることにより達成される。

【００１１】第１の回折格子の回折光によりマスクパターンの像を忠実に再生するためには、上記第１、第２及び第３の回折格子の周期方向は等しく、上記第１の回折格子の空間周期Ｐ１、第２の回折格子の空間周期Ｐ２、第３の回折格子の空間周期Ｐ３を、ほぼ$1/P3 = 1/P2 - 1/(M\cdot P1)$の関係を満たす様に設定する。

又、上記第１の回折格子の上記基板表面からの光学距離Ｚ１、及び、上記第２、第３の回折格子の上記マスク表面からの光学距離Ｚ２、Ｚ３は、ほぼ

$$(Z3 - Z2)/P2 = (Z3/M + Z1\cdot M)/P1$$

の関係を満たす様に設定する。さらに、$P2 \leqq 1/(1-2\cdot NA/M)$であることが望ましい。又、第１、第２、第３の回折格子の設置位置、各回折格子の透明基板の膜厚、及び第２の回折格子の周期を、上記マスク面と像面の間の収差が最小となるように設定することが好ましい。又、基板と第１の回折格子の間に、幅がＺ１ ＮＡ以下で、空間周期がほぼ２ Ｚ１ ＮＡの第１の遮光パターンを、又、前記マスクの直上又は直下に上記第１の遮光パターンとほぼ共役な領域を遮光する第２の遮光パターンを設けて露光領域を制限することが好ましい。さらに、必要に応じて、上記制限された露光領域を基板上で走査して露光するか、もしくはステップ状に移動しながら露光することが好ましい。これら各回折格子は、位相格子であることが好ましい。

【００１２】なお、前記回折格子は１次元回折格子とし、前記投影光学系の波面収差を、瞳上での上記回折格子の周期方向と垂直な方向の直径を軸として、線対称となるように収差補正することが好ましい。又、本発明は、マスクとして周期型位相シフトマスクを用いた場合、特に大きな効果を発揮する。さらに、必要に応じて回折格子の周期及び方向に応じて、微細なパターンの周期や方向を制限したり、パターン形状を補正することが望ましい。又、第１の回折格子と前記基板の間を屈折率ｎが１より大きい液体で満たし、前記投影光学系のＮＡを、

$$0.5 < NA < n/2$$

の範囲に設定すると、さらに微細なパターンの形成が可能となる。

【００１３】

【作用】本発明は、投影光学系の最終エレメントとウエハの間に回折格子を設け、ウエハ面へ入射する光ビームの入射角を大きくすることにより、実効的にＮＡを増大するのと等価な効果を得ようというものである。しかし、単純に従来光学系のレンズ-ウエハ間に回折格子を設けただけでは、本来像面上の１点に集約するはずの回折光は、像面上のばらばらな位置に散らばってしまい、マスクパターンの再生は到底困難である。従って、干渉の結果元のマスクパターンに忠実な像が再生されるように、光学系を再構成する必要がある。しかも実用性の観点から、これらの光学系は、従来の投影光学系を大きく改造することなく、しかも従来のマスクが使用可能であることが好ましい。本発明は、以下述べるようにこれらの要求を満足するものである。

【００１４】本発明の作用を説明するために、本発明による結像の原理を従来法と比較して説明する。本発明の一形態に基づく光学系における結像を図１に、又比較のため、従来投影露光光学系で従来マスク又は位相シフトマスクを、各々垂直に照明した場合と斜めに照明した場合の結像の様子を図２ａ、ｂ、ｃ、ｄに示す。いずれの図でも、２：１縮小光学系とコヒーレント照明、１次元パターンを仮定し、近軸結像近似した。

【００１５】まず、従来光学系で通常マスクを垂直照明した場合（図２ａ）、透過型マスク２１に垂直入射した光２２はマスク上のパターンにより回折され、回折光のうち投影光学系２３の瞳２４（絞り２０の内側）を通過した光線が像面２５上に収斂し、干渉してパターンを形成する。ここで、瞳を通過できる最大の回折角を与えるパターン周期を解像限界と定義すると、解像限界は、$\lambda/(2NA)$（但し$NA = \sin\theta o$）となる。さらに、この光学系に周期型位相シフトマスク２６を適用す

ると、図２ｂに示したように０次回折光が消滅して光軸２９（図中一点鎖線）に対して対称に回折光が生じる。このため、瞳を通過できる最大の回折角は２倍となり、解像限界はλ／（４ＮＡ）まで向上する。

【００１６】又、従来光学系に斜め照明を適用すると（図２ｃ、簡単のためマスク回折光の０次光２７が図中瞳の左端を通過すると仮定した）、マスク回折光のうち０次光を中心として正負どちらかの回折角をもつ片側成分（図では＋１次光２８）だけが瞳を通過し、像面に収斂する。垂直入射の場合の２倍の回折角を有する回折光が瞳を通過できるため、解像限界はやはりλ／（４ＮＡ）となる。しかし、回折スペクトルの片側しか用いないため、例えば孤立パターンの解像度は垂直照明の場合と変わらず、又、周期パターンの場合でもコントラストが低下する等の問題がある。さらに、マスクを周期型位相シフトマスク２６に変更すると複数の回折光は瞳を通過できないため、パターンは解像しない（図２ｄ）。

【００１７】次に、本発明の一形態に基づく光学系における結像を図１に示す。図１の光学系は、図２の従来光学系において、マスク１と投影光学系２の間に回折格子Ａ及び回折格子Ｂを、又、投影光学系２とウエハー４の間に回折格子Ｃを挿入したものである。ここで、回折格子Ａ、Ｂ、Ｃはともに位相格子とする。

【００１８】マスク１に垂直入射した光Ｒはマスク面で０次回折光Ｒ０、＋１次回折光Ｒ１、-１次回折光Ｒ１’に回折される。０次光Ｒ０は回折格子Ａ上の点Ａ０に達し、そこで-１次方向に回折された光は、回折格子Ｂ上の点Ｂ０で＋１次方向に回折された後、瞳３（絞り５の内側）の左端を経て回折格子Ｃ上の点Ｃ０で±１次方向に回折され、各々像面上の２点Ｑ、Ｐに達する。又、＋１次回折光Ｒ１は、回折格子Ａ上の点Ａ１に達し、そこで-１次方向に回折された光は回折格子Ｂ上の点Ｂ１で＋１次方向に回折された後、瞳３の右端を経て回折格子Ｃ上の点Ｃ１で±１次方向に回折され、やはり像面上の点Ｑ、Ｐに達する。一方、点Ａ０で＋１次方向に回折された０次光Ｒ０’と-１次回折光Ｒ１’に対する光路は、上述の２光線の光路と光軸６（図中一点鎖線）に対して対称となる。即ち、両者は、最終的に回折格子Ｃ上の点Ｃ０で±１次方向に回折され像面上の点Ｐ、Ｑ’に達する。従って、Ｐ点ではマスクで回折された０次光、及び＋１次、-１次光線の３つの光線が交わる。このことが、マスク回折角に依らないのは明らかである。従って、点Ｐでは回折像が忠実に再生される。

【００１９】従来法（図２ａ）と比べると、同一のＮＡ、倍率を持つ光学系を用いて、２倍の回折角をもつ回折光が瞳を通過できるため、実質的にＮＡを２倍したのと同様の効果が得られる。又、斜め照明（図２ｂ）では０次光を中心として正負どちらか片方の回折光しか像面で再生できないのに対して、本発明では両側の回折光を像面で再生できるため、斜め照明では困難であった孤立パターンの解像度向上が可能で、また周期パターンに対して大きなコントラストを得ることができる。さらに、本光学系に周期型位相シフトマスクを適用すると（図３ａ）、０次回折光が消滅して通常の倍の回折角を有する＋１次光Ｒ＋と-１次光Ｒ-が干渉する結果、最小解像度はλ／（８ＮＡ）となる。これは、これまで周期型位相シフトマスクや斜め照明を用いた場合の理論限界であるλ／（４ＮＡ）の半分であり、本発明により飛躍的な解像度の向上が可能となる。また、本光学系において斜め照明を適用した場合の結像の様子を図３ｂに示す。斜め照明により、片側のみに対して大きな回折角をもつ回折光Ｒ１"まで瞳を通過させることが可能となり、垂直照明時の最大２倍、即ちλ／（８ＮＡ）まで解像度を向上できる。又、マスク入射角の異なる様々な照明光を用いれば、従来光学系におけるのと全く同様に部分コヒーレント照明の効果を得ることができる。

【００２０】本発明の原理をフーリエ回折理論の立場から説明すると次のようになる（図４）。以下の説明では、光学系の倍率は１、回折格子は１次元位相格子で±１次回折光のみを考えるものとする。像面上の点Ｐから、回折格子Ｃを介して瞳３を見ると、回折により瞳は２つに分かれて見える（図４ａ）。各瞳の中には、各々ある特定の角度で瞳を通過するマスクフーリエ変換像が見える。一方、マスク側について考えると、マスクにより回折された光は回折格子Ａ及びＢで回折されて、瞳上に複数のマスクフーリエ変換像を形成する。このうち、ある特定の角度で瞳を通過したものが、上で見えた瞳の中に見えることになる（図４ｂ）。即ち、図４の場合、図４ｂの右のフーリエ回折像が図４ａの左側の瞳の中に見え、図４ｂの左のフーリエ回折像が図４ａの右側の瞳の中に見える。このとき、点Ｐで正しく像が再生されるための条件は次の２点である。

【００２１】（１）２つの瞳を介してマスク上の同一点のスペクトルが見えること。

【００２２】（２）２つのスペクトルが、２つの瞳の接点で連続して接続すること。

【００２３】言い替えれば、１つの連続するスペクトルを複数の瞳を介して見ることができるようにする必要がある。

【００２４】像から見て、回折格子Ｃを介してf'シフトした複数の瞳が見え、その各瞳の中に回折格子Ｂ及びＡを介してやはりf''シフトした複数のフーリエ回折像が見えるとすると、真の像の振幅分布$u(x)$は次式で表わされる。

【００２５】

$$u(x)=F[\Sigma p(f-f')\cdot\Sigma o(f-f'')]$$

$$f'=\pm SC$$

$$f''=\pm(SA-SB-SC)$$

ここで、$F[\ ]$はフーリエ変換、$p(f)$は瞳関数、$o(f)$はマスクフーリエ回折像、xは実空間座標、fは空

間周波数座標、ＳＡ、ＳＢ、ＳＣは回折格子Ａ、Ｂ、Ｃの回折角のsin（正弦）、Σは異なる回折次数に対する和を表す。従って、

ＳＡ＝ＳＢ＋ＳＣ

とすると、

ｆ"＝０

となり、ｆ'＝±ＳＣの両方に対して共にｆ"＝０となる項を得ることができる。即ち２つの瞳ｐ(ｆ±ＳＣ)を介して１つのスペクトルｏ(ｆ)を見ることができる。さらに、点Ｐでマスク上同一点に対する像を得るためには、マスク面と回折格子Ａ、Ｂ間の距離、及び回折格子Ｃと理想像面間の距離、各々ＺＡ、ＺＢ、ＺＣを、

ＳＡ(ＺＢ-Ｚ Ａ)＝ＳＣ(ＺＢ＋ＺＣ)

とすればよい。

【００２６】上の条件を近軸近似の下で縮小率Ｍ：１、像側開口数ＮＡの光学系に適用すると、回折格子Ａ、Ｂ、Ｃの周期ＰＡ、ＰＢ、ＰＣ、マスク面と回折格子Ａ、Ｂ間の距離ＺＡ、ＺＢ、回折格子Ｃと理想像面間の距離ＺＣをほぼ次のように設定すればよいことがわかる。

【００２７】１／ＰＡ=1／ＰＢ-１／(Ｍ ＰＣ)

(ＺＢ-Ｚ Ａ)／ＰＡ=(ＺＢ／Ｍ＋Ｍ・ＺＣ)／ＰＣ

さらに、本発明により十分な解像度向上効果を得るためには、

λ／ＮＡ≦ＰＣ≦$\sqrt{2}$ λ／ＮＡ

とすることが好ましい。

【００２８】回折格子Ａ、Ｂは、位相格子であることが好ましい。回折格子Ａ、Ｂが完全な位相格子でなく０次光を透過する場合、本方法より解像性に劣る従来光学系や斜入射光学系等の効果が本方法の効果に重なる。このため解像性が劣化する恐れがある。一方、回折格子Ｃは位相変調格子であっても振幅強度変調格子であっても構わない。回折格子Ｃの周期はかなり小さく、屈折率１．５のシリコン酸化膜を考えると格子パターンの断面縦横比はほぼ１程度となる。この場合、パターン断面での光の散乱効果に注意する必要がある。遮光パターンからなる回折格子の場合、遮光膜の厚さはかなり薄くできるため散乱の影響は低減できる。但し、後で述べるように、位相変調格子を用いる方が露光領域を広くすることができる。

【００２９】回折格子Ｂの基板側を屈折率ｎが１より大きい液体等で満たすと、この領域の波長と回折角のｓｉｎが１／ｎとなる。そこで、さらに回折格子Ｂの周期を細かくし、回折角を液体を満たさない場合と等しくすると、波長だけが１／ｎとなるため解像度も１／ｎに向上する。この場合、マスク側ではより回折角の大きな回折光が瞳を通過できる様マスク照明角を増大させる必要があるが、このとき回折角の小さな回折光は瞳を通過できなくなる。そこで、瞳の径をこれに応じて増大することが望ましい。このことは次のように言い替えることもできる。回折格子Ｂと基板の間の屈折率が１の場合、本発明で用いる投影光学系のＮＡを０.５以上にしても何ら解像度向上は得られない。sinθ＞０.５の角度θで周期λ／ＮＡの回折格子Ｂに入射する光線に対する回折角は９０度以上となり、エバネッセント波として回折格子表面に局在化してウエハーには伝わらないためである。一方、回折格子Ｂと基板の間の屈折率をｎとすると、sinθ＝ＮＡの角度で回折格子Ｂ（瞳の端を通過した０次光がウエハーに垂直入射するためには周期λ／ＮＡでなければならない）へ入射した光の回折角θ'は

sinθ'＝（λ／ＰＢ＋sinθ）／ｎ＝２ＮＡ／ｎ

となり、θ'＜９０度であるための条件は、ＮＡ＜ｎ／２となる。即ち、本発明を最大ＮＡ＝ｎ／２の光学系まで有効に適用できる。一般に液浸光学系は特別な光学設計を必要とするが、上述の様に本発明に適用した場合には何ら特別のレンズを必要としない。従って、半導体プロセスにおいて通常使用されているＮＡ０.６程度の投影レンズを用いて、回折格子Ｂと基板の間を水（屈折率約１．３）で満たして露光すれば、実質的にＮＡを１．２としたのと等価な効果が得られる。この場合、位相シフトマスクを用いれば、水銀ランプのｉ線の波長（３６５ｎｍ）でも、０.１μm以下の解像度が得られることになる。なお、本方法では、ウエハー近傍で干渉する光の入射角は極めて大きいため、結像性能は光の偏光状態に強く依存する。一般に、電場ベクトルが光の入射面に垂直な偏光状態を有する光の方が、高いコントラストの像を形成する上で望ましい。

【００３０】以上の議論は全て近軸近似を仮定し、回折格子の基板の屈折率を１としたものであり、実際には回折格子の基板の屈折率の効果や、回折格子により生じる収差の影響を厳密に考慮する必要がある。このため、各回折格子の設置位置等は若干変更する場合がある。複数の回折格子のパターンの周期方向は十分な精度で一致させることが好ましいことはいうまでもない。

【００３１】次に、本発明において注意すべき点について４点述べる。

【００３２】第１に、本光学系では従来露光法と比べて、一般に露光領域が制限される。図１より分かるように、像面上の点Ｑ、Ｑ’においても２光線が交わり互いに干渉して像が形成される。この像は、本来形成されるべきでない位置に生じる偽の像であり、一般に好ましくない。これを回避するため、図５ａに示すように像面５１の直上（ウエハーと回折格子Ｃの間）に遮光マスク５２を設けてこれらの偽の像を遮断することが望ましい。回折格子Ｃと遮光マスク５２は、図に示したように同一の石英基板５３の両面に形成することができる。（別々の基板上に形成しても構わない。）又、これと同時に同様にして、マスクの直上又は直下に上記遮光マスクとほぼ共役な領域を遮光するマスキングブレードを設ける等して、マスク照明領域を上記共役な領域に制限することが好ましい。１回の露光で転写可能な露光領域は、真の

像（P点）と偽の像（Q点）の間の距離（ほぼ2 NA・ZB）に相当する領域で、上記距離の2倍を周期として繰返し現れる。従って、露光可能な領域が露光したい面積より狭い場合には、図5bに示した様に、露光領域をウエハー上でスキャンすることが望ましい。この際、光学系の縮小率がM：1であったならば、マスクスキャン速度とウェハースキャン速度の比も厳密にM：1とすることが望ましいことはいうまでもない。これら露光領域をマスク及びウェハー上で同期スキャンする方法に関しては、既存の露光装置で用いられている方法をそのまま用いることができる。一方、露光可能領域が露光したい面積より大きい場合、即ち、真の像と偽の像の間の距離が例えば1個のチップをカバーする場合には、スキャンせずに露光可能である。露光領域の大きさは回折格子Bの設置位置によって決まり、回折格子Bを像面から離すほど、1つの露光領域の幅は増大する。但し、同時に転写不可能な領域の幅も増大するため、両者の割合はほぼ1：1のまま変わらない。偽の像の影響を排除するために、ウエハー上露光領域の幅Wは、W≦NA ZBとすることが望ましい。又、回折格子Bに振幅強度変調格子を用いた場合には、格子の0次回折光が真の像と偽の像の中間点にもう一つの偽の像を形成するため、露光領域は位相格子の場合のほぼ半分となる。

【0033】第2に、本方法では一般に露光強度が低下する。本方法でウェハー上で結像する光線は、光学系中に挿入された回折格子により回折された光線のうち特定の回折次数の光だけを用いている。従って、回折格子を通過する度に露光に寄与する光強度は低下することになる。また、上で述べたようにマスク及びウェハー上で露光領域を制限していることも、スループット低下の原因となる。このため、本方法では十分に強度の強い光源を用いる、感度の高い化学増幅系レジスト等のレジスト材料を用いる等の対策を行うことが望ましい。

【0034】第3に、前の説明で示したように、瞳上には、f"＝0の望ましい回折像に加えて、f"＝±2(SA＋SB)だけシフトしたフーリエ変換像が生じる。これは、マスクパターンの高次スペクトルが実質的に低い空間周波数領域に重なってしまうことを意味し、一般に好ましくない。図1の光学系においてこれを避けるためには、

PA≦1／（1-2 NA／M）

とすればよい。この場合、マスクで回折角2・NA／Mで回折された回折光（図1中R1）に対する回折格子Aによる＋1次方向の回折光（図1中A1から発する点線に相当）は存在できないからである。

【0035】第4に、本発明の光学系では、回折格子導入に伴う収差に注意する必要がある。回折格子により発生する収差について、図6を用いて説明する。マスク通過後の光線が光軸と回折格子の周期方向を含む面内にあると仮定する（例えば、1次元パターンとコヒーレント照明）。図6aの光学系が無収差であるためには、例えば$OX_1X_2X_3I$、$OY_1Y_2Y_3I$、及び$OZ_1Z_2Z_3I$の各光路長の差が0でなければならない。しかし、これらの間に光路長差があるとこれが収差となる。ここで投影光学系は収差0の理想的な光学系であると仮定すると、$X_2X_3＝Y_2Y_3＝Z_2Z_3$より、$OX_1X_2＋X_3I$、$OY_1Y_2＋Y_3I$、及び$OZ_1Z_2＋Z_3I$の差が収差となる。瞳の直径を横切る$OX_1X_2X_3I$から$OZ_1Z_2Z_3I$に至る光路の波面収差を$OY_1Y_2Y_3I$を基準として規格化した瞳半径座標sに対してプロットすると図6bの実線のようになる。マスク通過後光軸に対して＋の角度を有する光線に対する収差w＋(s)は瞳上で一般に非対称となることがわかる。同様に光軸に対して-の角度を有する光線に対する収差w-(s)は、光学系の対称性からw＋(s)と瞳を中心として対称となる。本発明では、＋方向に回折した光と-方向に回折した光を同時にウエハー上で干渉させる必要があるから、両者に対する収差を同時に補正する必要がある。しかし、図6bからわかるように、＋方向と-方向に回折した光に対する瞳上収差が一致しないことから、これらを同時に投影光学系で補正することは原理的に困難となる。従って、これらの収差は、マスクと投影光学系の間、又はウエハーと基板の間で補正することが好ましい。これは、一般に次のような方法で行うことができる。

【0036】w＋(s)とw-(s)が等しければ、これを投影光学系で補正することが可能である。そこで、Δw(s)＝{w＋(s)}－{w-(s)}を、瞳上（図6では-1≦s≦1の範囲）で波長と比べて十分に小さい量δに抑えればよい。一方、Δw±(s)は、各回折格子の設置位置と周期、回折格子を支える基板の厚さと屈折率、基板と回折格子の相対位置関係等のパラメータxi（i＝1、2、…）の関数として表される。そこで、問題は、-1≦s≦1の範囲で、Δw(s、xi)＜δを満たすxiを求めることに帰着する。実際の最適化の例については実施例で述べる。いずれにせよ、このようにして、マスク通過後光軸に対して±の角度を有する光線に対する収差を瞳上で対称な形とすれば、これを投影光学系において補正することができる。又、さらに上で述べた方法により収差自体を十分に抑制することができれば、より好ましい。

【0037】以上、簡単のためマスクパターンとして1次元のパターンを想定したが、実際には2次元パターンが存在したり、部分コヒーレント照明を用いた場合には、マスク通過後の光線は、光軸と回折格子の周期方向を含む面内に収まらず、瞳上の様々な点に向かう。この場合、Δwとして、瞳上の2次元座標（s、t）の関数Δw(s、t)＝{w＋(s、t)}－{w-(s、t)}を考え、瞳面内で、Δw(s、t、xi)＜δを満たすxiを求めればよい。これは、w±(s、t)を瞳上でs＝0に対してできるだけ対称な形とすることを意味する。

【0038】さらに、全ての方向に対して本発明の効果を得るためには、例えば図7a、bに示すように各回折格子を2次元回折格子とすることが考えられる。この場合、見かけ上の瞳の形は4回対称となる。しかしながら、上で述べた事情により、互いに垂直な2組の瞳に対して瞳上で同時に収差補正することは、光学系のNAが小さい場合を除いてやや困難である。このため、マスク上ですべての方向に対して同等に本発明の効果を得ることはやや難しく、図8のような1次元回折格子を用いるのがより現実的である。図8a、b、cは3つの代表的な回折格子と見かけ上の瞳形状である。図8aの場合、x方向のパターンに対して実質的なNAは2倍近く増大するが、y方向のパターンに対しては減少する。図8bの場合、x方向のパターンに対して実質的なNAは√2倍となり、y方向のパターンに対しては1／√2となる。図8cの場合、x，y両方向ともNAは√2倍となるが、x，y方向以外に対する結像性能は著しくパターン方向に依存すると考えられる。何れの場合にも、マスク上でパターンのレイアウトルール等に方向による制限を課すことが望ましい。

【0039】結像性能のパターン方向依存性をなくすためには、図8a、b、cの条件を、各々例えば90度回転させて多重露光を行ってもよい。特に、図8cにこれを適用した場合には、x，y方向以外に対するパターン方向依存性を抑制し、かつ像コントラストを犠牲とせずにx，y両方向ともNAを√2倍したのと同等な像を得ることができる。但し、回折格子を90度回転させた場合、収差特性も90度回転する。そこで、収差補正を瞳フィルターを用いて行い、回折格子とともにこれを90度回転させる等の対策を施すことが望ましい。なお、収差抑制が困難な場合には、必要に応じて瞳にスリットフィルターを設ける等してもよい。

【0040】図3に示したように周期型位相シフトマスクを完全コヒーレント照明した場合には、ウエハー近傍で干渉する±1次光の光路は光軸に対して常に対称であり、各々の光路長は等しい。従って、光学系が収差補正されていなくても微細パターン形成可能である。即ち、完全コヒーレント照明下で周期型位相シフトマスクを用いる場合には、図7に示したような2次元回折格子が使用可能で、位相シフトマスクの効果をパターン方向に依らず最大限に発揮することができる。様々なパターンの混在するマスクパターンを転写する場合には、微細周期パターンのみを上記方法で露光し、その後その他の部分を従来露光法で露光すればよい。

【0041】また、上記収差は一般にNAの値とともに急激に増大する。このため、NA0.1～0.2程度の光学系では比較的問題とならない。従って、低NA・低倍率の大面積用露光装置や、反射型の軟X線縮小投影露光装置等に適用する場合には、上で述べたような様々な制約が軽減される。

【0042】以上、本発明は、0次回折光線を中心としたフーリエ回折像の左右片側を各々別々に瞳を通過させ、これを像側で合成するものであるといえる。この考え方自体は、前述の文献に論じられている様に既に光学顕微鏡に応用されているものであるが、これを縮小投影光学系の上で実現可能な光学系の構成はこれまで考案されていなかった。本発明は、これを縮小投影露光系においてたくみに実現したものに他ならない。即ち、図1の光学系は、投影光学系とウエハの間に回折格子を設け、ウエハ面へ入射する光ビームの入射角を大きくするとともに、ウエハ面干渉の結果元のマスクパターンに忠実な像が再生されるように、光学系を構成したものである。本発明は、屈折光学系、反射光学系、及びこれらの組合せ、縮小光学系、等倍光学系等、様々な投影光学系に適用できる。これらの光学系を用いてマスクパターンをウェハー上へ露光する場合の露光方法としても、一括転写、スキャン方式、ステップアンドリピート、ステップアンドスキャン等のいずれにも適用可能である。又、以上の説明より明らかなように、本発明は純粋に幾何光学的な効果に基づいている。従って、前述のモアレ縞を用いる方法における様なエバネッセント光利用に起因する問題点は生じない。又、回折格子はウエハーより離して設置可能で、しかも同期スキャン等の必要もないため、はるかに容易に実現可能である。

【0043】

【実施例】

（実施例1）本発明に基づき、NA＝0．45、光源波長λ＝248nm、縮小率4：1のスキャン型KrFエキシマレーザ投影露光装置を、図9に模式的に示すように改造した。即ち、マスクステージ100上に設置したマスク101と投影光学系102の間に、両面に位相格子パターンを有する透明石英板103を挿入した。又、ウエハーステージ（試料台）104上に設置したウエハー105と投影光学系102の間に、片面に遮光パターン、もう片面に位相格子パターンを有する透明石英板106を、遮光パターンの側がウエハーに対面するように挿入した。遮光パターンは幅300μm周期1mmのCrパターン、位相格子パターンは周期＝λ／NAのSi酸化膜パターンとした。マスク側透明石英板103上の位相格子パターンの周期は、ウエハー側の4倍である。Si酸化膜厚は、膜の存在部と存在しない部分を透過した光の位相が180度ずれるように設定した。これらのパターンはEBリソグラフィを用いて、いわゆるクロムレス位相シフトマスクの作製プロセスと同様にして形成した。又、マスクの照明光学系107側に、幅1.2mm、周期＝4mmの遮光パターンを有する透明石英板108を設けた。上記遮光パターンの遮光領域は、ウエハー側透明石英板106上の遮光パターンと共役となるように設定した。

【0044】透明石英板103両面の位相格子の周期、

各透明石英板の膜厚と設置位置等は、作用の項に述べた意味における投影光学系瞳上の収差が軸対称となるよう、光線追跡プログラムの最適化機能を用いて最適化した。さらに、上記軸対称な収差補正のため、収差補正フィルター１０９を投影光学系の瞳位置に挿入した。ここで、収差補正フィルター１０９は、主に上記回折格子の周期方向と垂直な方向の非点収差を補正するものである。なお、これらの回折格子等を有する透明石英板と収差補正フィルターは、いずれも交換可能で、所定の位置にすみやかに設定できるようにした。又、透明石英板の位置ぎめを正確に行うために、各石英基板のホルダー（図示せず）は微動機構（図示せず）を有し、各石英基板の位置を計測してこれを所望の位置に設定することができる。さらに、ウエハーステージ１０４上に設けたオートフォーカスモニター（図示せず）により像をモニターすることにより、像面上で最適な結像特性が得られるように、モニター結果をフィードバックして各石英基板の位置を調整することも可能とした。なお、投影光学系自体をあらかじめ上記回折格子に対して収差補正を施してもよく、この場合には収差補正フィルターは必要ない。露光は、マスク及びウエハーを同期スキャンしながら行なった。ステージ制御系１１０は、マスクステージ１００とウエハーステージ１０４を、各々４：１の速度比で同期走査する。

【００４５】上記露光装置を用いて、周期型位相シフトパターンを含む様々な寸法のパターンを有するマスクを、化学増幅系ポジ型レジスト上へ転写した。露光後所定の現像処理を行い、走査型電子線顕微鏡で観察した結果、上記位相格子の周期方向（ｘ方向）に対して周期型位相シフトマスクにより寸法９０ｎｍ（周期１８０ｎｍ）のレジストパターンが形成できた。一方、上記方向と垂直な方向（ｙ方向）の解像度は、位相シフトマスクを用いて寸法１４０ｎｍ（周期２８０ｎｍ）程度であった。そこで、次に、上記３枚の位相格子及び収差補正フィルターを９０度回転して同じマスクを露光してレジストパターンを形成したところ、ｘ方向とｙ方向に対する解像度は逆転した。

【００４６】なお、上の実施例は、光学系の種類、ＮＡ、光源波長、縮小率、レジスト、マスクパターンの種類と寸法、回折格子と遮光パターンの周期や設置位置等、きわめて限定されたものであるが、これらの各種条件は本発明の主旨に反しない範囲内で様々に変更可能である。

【００４７】（実施例２）次に、回折格子導入に伴う収差の影響が最小となるよう、光学系を最適化した例を示す。図１０の光学系において、Ｏ、Ｉは、回折格子を導入した光学系のマスク面と像面、Σ、Σ’は回折格子を導入しない投影光学系のマスク面と像面、ｈｉ（ｉ＝１～６）は図中の距離を示す。回折格子Ａ、Ｂ、Ｃとウエハー直上の遮光パターンは実施例１同様透明石英基板の両面に形成した。このとき、マスク通過後に光軸に対して±の角度を有する光線に対する横収差$w\pm(s)$は、規格化瞳半径座標ｓの関数として次のように表される。

【００４８】

$$w\pm(s)=wu\pm(s)+ws\pm(s)$$

$$wu\pm(s)=C_1h_1+C_2(s_1)h_2+C_5h_5+C_6h_6$$

$$ws\pm(s)=C_3h_3+C_4h_4$$

$$C_1=\tan[(s\pm s_0)/M]/M,\quad C_2=\tan[\pm(s_1/n)-(s\pm s_0)/(nM)]/M,$$

$$C_3=\tan[s/M]/M,\quad C_4=\tan(s),$$

$$C_5=\tan[(s\pm s_0)/n],\quad C_6=\tan(s\pm s_0)$$

ここで、ｗｕは瞳上でｓ＝０に対して非対称な成分、ｗｓは対称な成分を表す。但し、s_0＝ＮＡ、s_1＝λ／ＰＡである。s_0（ＮＡ）、縮小倍率Ｍ、透明石英基板の屈折率ｎはシステム固有の値とすると、上式は７つの最適化パラメータ、ｈｉ（ｉ＝１～６）及びs_1を含む。そこで、$wu\pm(s)$、$ws\pm(s)$に対して収差を最小とすべく７つの拘束条件を課すことにより、これらの値を最適化した。いくつかのＮＡに対する最適化結果の一例を表１に示す。但し、収差はh_5／λを単位とする波面収差で表した。

【００４９】

【表１】

表1

NA	0.1	0.2	0.3	0.4
h_1/h_5	17.352	16.167	14.263	11.343
h_2/h_5	0.529	0.995	1.343	1.507
h_3/h_5	24.014	22.800	20.137	14.819
h_4/h_5	0.368	0.485	0.652	0.920
h_6/h_5	0.01	0.01	0.01	0.01
s1	1.225	1.259	1.300	1.349
$w_{max}(s)$	5×10^{-9}	3×10^{-7}	4×10^{-6}	5×10^{-6}
$w^u_{max}(s)$	1×10^{-12}	1×10^{-9}	2×10^{-7}	1×10^{-5}

$$w^u_{max}(s) = \max[w+(s) - w-(s)]$$

$$s1 = n\lambda/PA$$

【0050】表からわかるように、ＮＡ＝0.4においても十分に収差を抑えることが可能であった。同様の最適化は、回折格子Ａ、Ｂが各々別の透明基板上に設けられている場合等、様々な配置に対して行うことができる。さらに、新たな透明基板や回折格子を導入することにより最適化のパラメータを増やすことにより、さらに厳しい収差条件を満足させることができる。

【００５１】（実施例３）次に、実施例１に示した露光装置を用いて、０．１μｍ設計ルールのＤＲＡＭを作成した例について述べる。図１１は、上記デバイスの作製工程を露光プロセスを中心に示したものである。

【００５２】まず、ウエル等（図示せず）を形成したＳｉ基板２０１上にアイソレーション２０２及びゲート２０３を形成した（図１１ａ）。アイソレーション及びゲートパターンは周期型位相シフトマスクを用い、実施例１に示した露光装置により露光した。ここで、シミュレーションにより周期パターンの周辺部においてパターン形状が歪む部分が生じることが予測されたため、この不要部分を除去するためのマスクを用意した。上記マスクを上記露光を行ったものと同一レジスト膜に対して従来露光装置を用いて重ね露光した後現像して、回路性能上好ましくない部分を除去した。なお、上記不要部分を除去せずに、回路的に無視することによって対処してもよい。

【００５３】次に、キャパシター２０４及びコンタクトホール２０５を形成した（図１１ｂ）。コンタクトホールのパターン露光には、電子線直接描画法を用いた。次に、第１層配線２０６、スルーホール（図示せず）、第２層配線２０７を形成した（図１１ｃ）。第１層配線（０．１μｍＬ／Ｓ）は周期型位相シフトマスクと実施例１に示した露光装置を用いて露光した。但し、ここで各回折格子の方向と寸法を図９ｃに示したものに変更し、さらにこれを９０度回転させて多重露光を行った。このとき、同時に収差補正フィルター１０９も回折格子とともに９０度回転させた。これにより、縦横の両方向に延びる配線に対して方向依存性なしに０．１μｍＬ／Ｓを形成できた。スルーホールの形成はコンタクトホールと同様、電子線直接描画法を用いた。以降の多層配線パターン及びファイナルパッシベーションパターンは０．２μｍルールで設計されており、本発明を用いない通常のＫｒＦエキシマレーザ投影露光法により形成した。なお、デバイスの構造、材料等に関し、上記実施例で用いたものにとらわれず変更可能である。

【００５４】（実施例４）次に、本発明の別の実施例として、本発明を分布帰還型（ＤＦＢ）レーザーの製作に適用した例について述べる。露光装置には、ＮＡ０．５のＡｒＦエキシマレーザ縮小投影露光装置を実施例１同様にして改造したものを用いた。従来の１／４波長シフトＤＦＢレーザーの作製工程において、電子線描画法等を用いて形成していた周期１４０ｎｍの回折格子を、周期型位相シフトマスクと上記露光装置を用いて形成した。これにより、電子線描画法等を用いて作製したものとほぼ同等の性能を有するＤＦＢレーザーを、より短期間で製作することが可能となった。

【００５５】

【発明の効果】以上、本発明によれば、照明光学系を介して光をマスクに照射し、マスクパターンを投影光学系により基板上へ結像させてパターンを形成する際、上記基板と上記投影光学系の間に上記基板と平行に回折格子を設けるとともに、上記回折格子により回折された光の干渉により基板面近傍でマスクパターンの像が再生されるように、投影光学系とマスクの間又はマスクと照明光学系の間に回折格子又は結像光学系を設けることにより、従来露光装置の解像限界を越えた微細パターンの形成が可能となる。具体的には、投影光学系のＮＡを変えることなしに、そのＮＡを実質的に最大２倍にしたのとほぼ同等の効果が得られる。これにより、従来露光装置の光学系の基本的な構成を大きく変更することなく、大きな露光フィールドと高い解像力が得られ、大量生産に適した縮小投影光リソグラフィを用いて、寸法０.１μｍクラスのＬＳＩの製造が可能となる。

【００５６】

【図面の簡単な説明】

【図１】本発明による一光学系の結像の原理を幾何学的に示す模式図である。

【図２】各種従来露光法による結像の原理を示す模式図である。

【図３】本発明による一光学系に位相シフトマスク又は斜め照明法を適用した場合の結像の原理を示す模式図である。

【図４】本発明による一光学系の結像の原理を回折光学的に示す模式図である。

【図５】本発明による一光学系の一部分と露光方法の一例を示す模式図である。

【図６】本発明による一光学系の特性を示す模式図である。

【図７】本発明で用いる光学部品とそれにより得られる効果を示す模式図である。

【図８】本発明で用いる光学部品とそれにより得られる効果を示す模式図である。

【図９】本発明の一実施例による露光装置の構成を示す模式図である。

【図１０】本発明の別の実施例の特性を示す図である。

【図１１】本発明の別の実施例によるデバイス作製工程を示す模式図である。

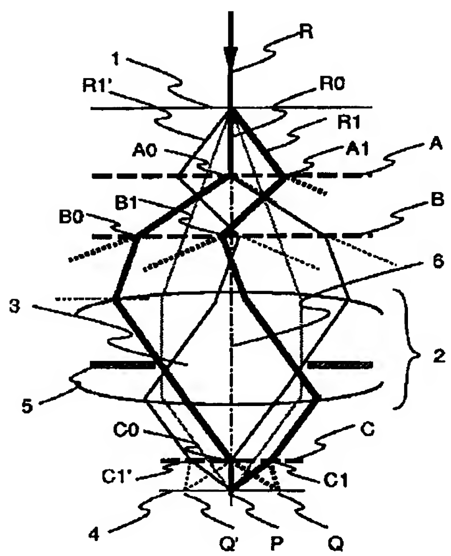
【符号の説明】

１…マスク、２…投影光学系、３…瞳、４…ウエハー、５、２０…絞り、６、２９…光軸、Ａ、Ｂ、Ｃ…回折格子、Ｒ…光、Ｒ０、Ｒ０’…０次回折光、Ｒ１、Ｒ＋、Ｒ１”…＋１次回折光、Ｒ１'、Ｒ-…-１次回折光、

A０、A１…回折格子A上の点、B０、B１…回折格子B上の点、C０、C１、C１’…回折格子C上の点、Q、P、Q’…像面上の点、２１…従来透過型マスク、２２…光、２３…投影光学系、２４…瞳、２５…像面、２６…周期型位相シフトマスク、２７…マスク回折光の０次光、２８…＋１次光、５１…像面、５２…遮光マスク、５３…石英基板、O…マスク上の点、X_1、Y_1、Z_1…回折格子A上の点、X_2、Y_2、Z_2…回折格子B上の点、X_3、Y_3、Z_3…回折格子C上の点、I…像面上の点、１００…マスクステージ、１０１…マスク、１０２…投影光学系、１０３…透明石英板、１０４…ウエハーステージ（試料台）、１０５…ウエハー、１０６…透明石英板、１０７…照明光学系、１０８…透明石英板、１０９…収差補正フィルター、１１０…ステージ制御系、２０１…Ｓｉ基板、２０２…アイソレーション、２０３…ゲート、２０４…キャパシター、２０５…コンタクトホール、２０６…第１層配線、２０７…第２層配線。

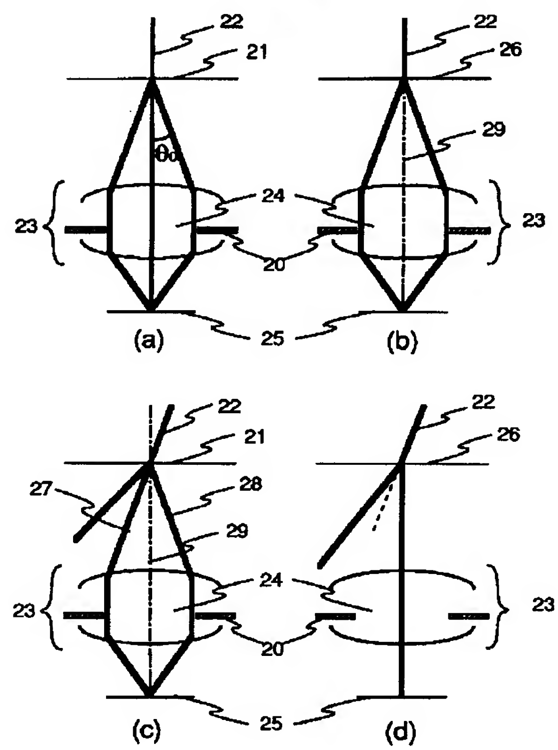
【図１】

図１



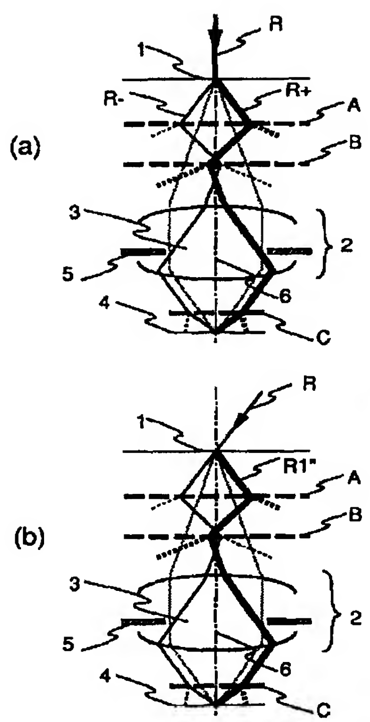
【図２】

図２



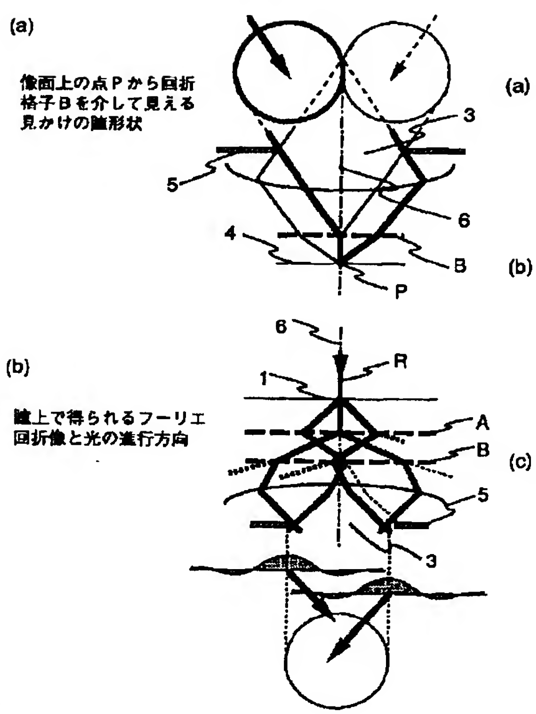
【図3】

図3



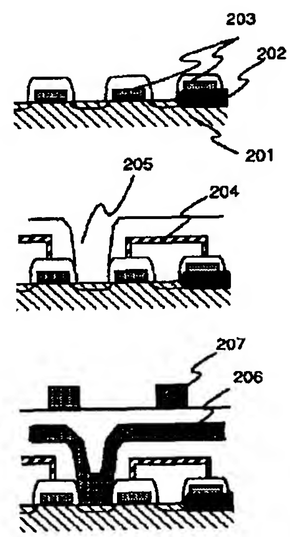
【図4】

図4



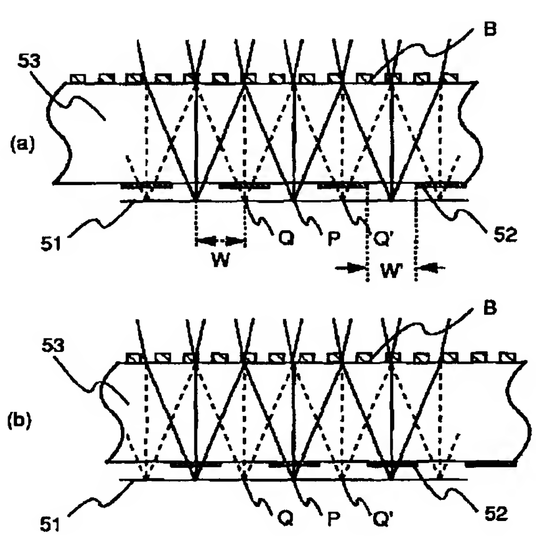
【図11】

図11



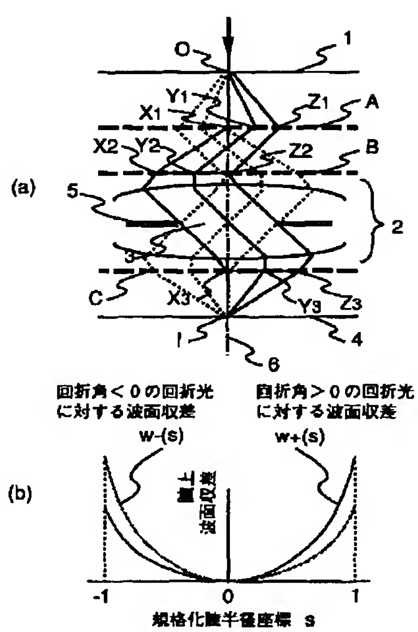
【図5】

図5



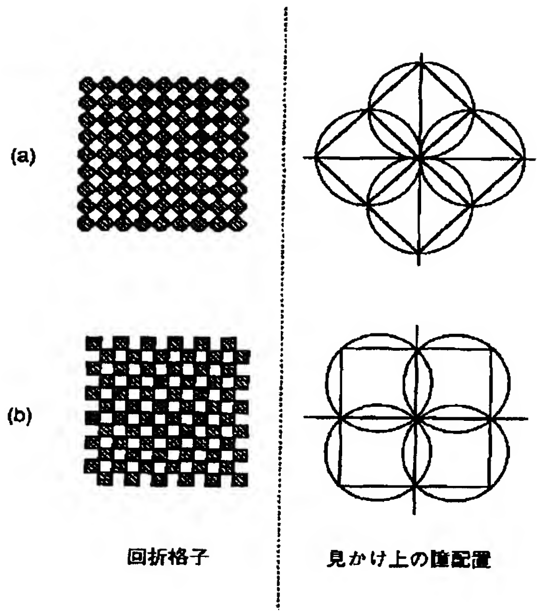
【図6】

図6



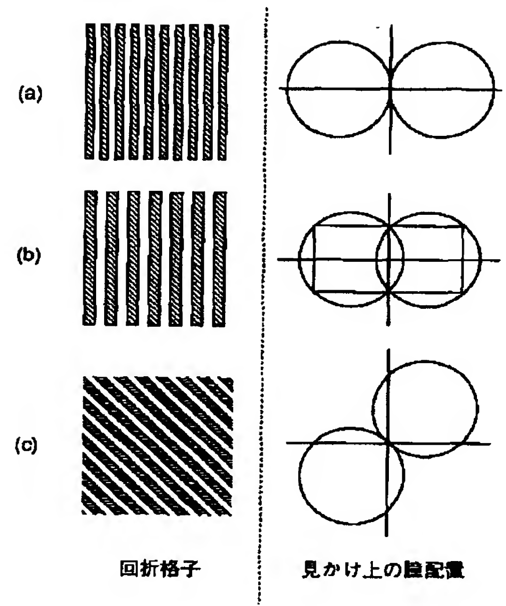
【図7】

図7



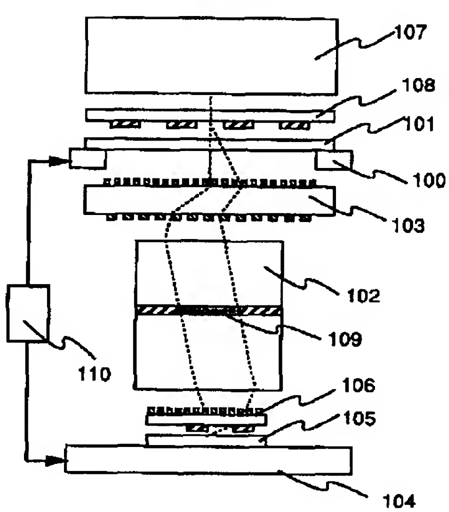
【図8】

図8



【図9】

図9



【図10】

図10